IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

CALLAWAY GOLF COMPANY,	)	
	)	
Plaintiff,	)	C.A. No. 07-367-SLR
	)	
v.	)	**JURY TRIAL DEMANDED**
	)	
ACUSHNET COMPANY,	)	**PUBLIC VERSION**
	)	
Defendant.	)	

FOURTH AMENDED ANSWER OF ACUSHNET COMPANY TO COMPLAINT, COUNTERCLAIMS AND JURY DEMAND

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For its Third Amended Answer and Counterclaims to the Complaint and Demand for Jury Trial by Callaway Golf Co. ("Callaway"), Acushnet Golf Company ("Acushnet") responds and alleges as follows:

PARTIES

1. Acushnet is without knowledge or information sufficient to form a belief as to the truth of the allegations set forth in paragraph 1.

2. Acushnet admits the allegations set forth in paragraph 2.

3. Acushnet admits the allegations set forth in paragraph 3.

4. Acushnet admits the allegations set forth in paragraph 4.

JURISDICTION AND VENUE

5. Acushnet admits that jurisdiction for patent infringement actions is based on 28 U.S.C. §§ 1331 and 1338(a), but otherwise denies the remainder of the allegations of paragraph 5.

6. Acushnet admits that it is incorporated in Delaware and that it is doing and has done business in this district, but otherwise denies the remainder of the allegations of paragraph 6.

7. Acushnet admits that venue for patent infringement actions is based on 28 U.S.C. §§ 1400(b), but otherwise denies the remainder of the allegations of paragraph 7.

BACKGROUND

8. Acushnet is without knowledge or information sufficient to form a belief as to the truth of the allegations set forth in paragraph 8.

9. Acushnet denies the allegations set forth in paragraph 9.

10. Acushnet admits that U.S. Patent Nos. 6,348,015; 6,478,692; 6,669,579; 6,685,576; and 6,949,032 were issued to John Kosmatka and that Callaway is listed as the

assignee. Acushnet is without knowledge or information sufficient to form a belief as to the truth of the remaining allegations set forth in paragraph 10.

11. Acushnet is without knowledge or information sufficient to form a belief as to the truth of the allegations set forth in paragraph 11.

12. Acushnet admits that it makes and sells golf clubs under the Titleist® and Cobra® brands, including the King Cobra 454 Comp, King Cobra F Speed, King Cobra HS9 F Speed, King Cobra HS9 M Speed, King Cobra LD F Speed, Titleist 905R, Titleist 905S and Titleist 905T clubs. Acushnet denies remaining allegations set forth in paragraph 12.

THE 1996 SETTLEMENT AGREEMENT

13. Acushnet admits that it and Spalding World Wide Sports, Inc. ("Spalding") were engaged in patent litigation in 1996. Acushnet admits that it and Spalding entered into a settlement agreement in or about August 1996, which agreement contained a dispute resolution provision. Acushnet further admits that the quoted language in paragraph 13 is contained in the settlement agreement, but denies that the agreement references Magistrate Judge Thynge. Acushnet denies the remaining allegations set forth in paragraph 13.

14. Acushnet admits that Callaway purported to invoke the dispute resolution procedures in the settlement agreement in or about August 2004, and that the quoted language in paragraph 14 can be found in the settlement agreement. Acushnet denies the remaining allegations set forth in paragraph 14.

15. Acushnet admits that it engaged in settlement discussions with Callaway over an approximate eighteen-month period, which negotiations included senior executives, a third-party professional mediator and Magistrate Judge Thynge. The remaining allegations set forth in paragraph 15 are denied.

16. Acushnet admits filing four *inter partes* reexamination requests with the PTO, numbers 95/000120-123. Acushnet denies the remaining allegations set forth in paragraph 16, and specifically denies that the submission of the reexaminations constitutes a breach of the settlement agreement.

17. Acushnet admits that Callaway filed a lawsuit against Acushnet in or about February 2006, in which Callaway accused Acushnet of infringing four patents. Acushnet denies the remaining allegations set forth in paragraph 17.

18. Acushnet admits the allegations set forth in paragraph 18.

19. Acushnet admits that it opposed Callaway's motion to amend, and that the quoted language in paragraph 19 is contained in that opposition. Acushnet denies the remaining allegations set forth in paragraph 19.

20. Acushnet admits the allegations set forth in paragraph 20.

21. Acushnet admits that Callaway sent it a letter dated April 3, 2007, but denies that that letter disclosed or described the alleged dispute, the patents allegedly asserted, or the products allegedly involved.

22. Acushnet admits sending letters to Callaway dated April 9 and April 19, 2007. Acushnet denies the remaining allegations set forth in paragraph 22.

23. Acushnet denies the allegations set forth in paragraph 23.

COUNT I

24. Paragraphs 1 through 23 are reiterated and herein incorporated by reference.

25. Acushnet admits that United States Patent No. 6,348,015 ("the '015 patent") is entitled "Golf Club Head Having a Striking Face with Improved Impact Efficiency" and was issued on February 19, 2002, and lists Callaway as an assignee of the patent, and admits that a

purported copy of the '015 patent is attached as Exhibit A, but denies the remaining allegations of paragraph 25.

26. Acushnet denies the allegations set forth in paragraph 26. Acushnet has not and is not infringing the claims of the '015 patent, either literally or under the doctrine of equivalents, nor is it infringing pursuant to the reverse doctrine of equivalents.

27. Acushnet denies the allegations set forth in paragraph 27.

28. Acushnet denies the allegations set forth in paragraph 28.

COUNT II

29. Paragraphs 1 through 23 are reiterated and herein incorporated by reference.

30. Acushnet admits that United States Patent No. 6,478,692 ("the '692 patent") is entitled "Golf Club Head Having a Striking Face with Improved Impact Efficiency" and was issued on November 12, 2002, and lists Callaway as an assignee of the patent, and admits that a purported copy of the '692 patent is attached as Exhibit B, but denies the remaining allegations of paragraph 30.

31. Acushnet denies the allegations set forth in paragraph 31. Acushnet has not and is not infringing the claims of the '692 patent, either literally or under the doctrine of equivalents, nor is it infringing pursuant to the reverse doctrine of equivalents.

32. Acushnet denies the allegations set forth in paragraph 32.

33. Acushnet denies the allegations set forth in paragraph 33.

COUNT III

34. Paragraphs 1 through 23 are reiterated and herein incorporated by reference.

35. Acushnet admits that United States Patent No. 6,669,579 ("the '579 patent") is entitled "Golf Club Head Having a Striking Face with Improved Impact Efficiency" and was issued on December 30, 2003, and lists Callaway as an assignee of the patent, and admits that a

purported copy of the '579 patent is attached as Exhibit C, but denies the remaining allegations of paragraph 35.

36. Acushnet denies the allegations set forth in paragraph 36. Acushnet has not and is not infringing the claims of the '579 patent, either literally or under the doctrine of equivalents, nor is it infringing pursuant to the reverse doctrine of equivalents.

37. Acushnet denies the allegations set forth in paragraph 37.

38. Acushnet denies the allegations set forth in paragraph 38.

COUNT IV

39. Paragraphs 1 through 23 are reiterated and herein incorporated by reference.

40. Acushnet admits that United States Patent No. 6,685,576 ("the '576 patent") is entitled "Golf Club Head Having a Striking Face with Improved Impact Efficiency" and was issued on February, 2003, and lists Callaway as an assignee of the patent, and admits that a purported copy of the '576 patent is attached as Exhibit D, but denies the remaining allegations of paragraph 40.

41. Acushnet denies the allegations set forth in paragraph 41. Acushnet has not and is not infringing the claims of the '576 patent, either literally or under the doctrine of equivalents, nor is it infringing pursuant to the reverse doctrine of equivalents.

42. Acushnet denies the allegations set forth in paragraph 42.

43. Acushnet denies the allegations set forth in paragraph 43.

COUNT V

44. Paragraphs 1 through 23 are reiterated and herein incorporated by reference.

45. Acushnet admits that United States Patent No. 6,949,032 ("the '032 patent") is entitled "Golf Club Head Having a Striking Face with Improved Impact Efficiency" and was issued on September 27, 2005, and lists Callaway as an assignee of the patent, and admits that a

purported copy of the '032 patent is attached as Exhibit E, but denies the remaining allegations of paragraph 45.

46. Acushnet denies the allegations set forth in paragraph 46. Acushnet has not and is not infringing the claims of the '032 patent, either literally or under the doctrine of equivalents, nor is it infringing pursuant to the reverse doctrine of equivalents.

47. Acushnet denies the allegations set forth in paragraph 47.

48. Acushnet denies the allegations set forth in paragraph 48.

DEFENSES

Acushnet asserts the following defenses:

49. Callaway has failed to state a claim upon which relief may be granted.

50. Acushnet is not infringing and has never infringed any claim of any of the '015, '692, '579, '576 or '032 patents ("the Asserted Patents"), either literally, under the doctrine of equivalents, or under the reverse doctrine of equivalents.

51. Each of the claims of the Asserted Patents is invalid due to failure to comply with the requirements of patentability as set forth in Title 35 U.S.C. *et seq*., including, but not limited to, §§ 101, 102, 103 and 112.

52. Callaway's infringement claims are barred by the doctrine of laches.

53. Callaway's infringement claims are barred by the doctrine of estoppel.

54. Callaway's patents are unenforceable due to patent misuse.

55. Callaway's infringement claims are barred by the doctrine of unclean hands.

56. Callaway's infringement claims are barred because conditions precedent to bringing this suit were not satisfied, in that Callaway has maintained that the dispute resolution procedures in the settlement agreement apply to the present dispute and has admitted that it has not followed those procedures solely because of its wrongful claim that Acushnet has breached

the agreement. Acushnet has not breached the settlement agreement. Based on Callaway's assertions, the settlement agreement provides that a lawsuit may not be filed until the dispute resolution procedures contained therein have been exhausted.

57. Based on Callaway's assertions, Callaway's infringement claims are barred by its breach of the settlement agreement.

58. Callaway's patents are unenforceable as the result of inequitable conduct before the United States Patent and Trademark Office ("PTO"). During the prosecution of each of the patents-in-suit, Callaway's in-house attorneys who prepared and/or prosecuted Callaway's applications, including Mr. Michael Catania ("Catania") and Ms. Elaine H. Lo ("Lo"), the named inventor, John Kosmatka ("Kosmatka"), and/or other persons at Callaway, the assignee of the Callaway patents, who were substantively involved in the preparation and/or prosecution of Callaway's applications had a continuing duty of candor and good faith to disclose to the PTO all information known that is material to patentability, pursuant to the United States patent laws and regulations, including 37 C.F.R. § 1.56. Acushnet is informed and believes, and thereupon alleges, that these persons violated their duty of candor and good faith and that Callaway's patents are unenforceable due to inequitable conduct for the following reasons: (1) false statements in the specification; (2) failure to cite material information relating to prior art golf clubs; (3) failure to cite material prior art when filing a continuation-in-part patent application; (4) failure to cite information relating to the Liquid Metal golf club described in the specification; (5) failure to cite information relating to the United States Golf Association's ("USGA's") testing for "spring-like effect"; and (6) failure to cite to treatises relating to natural frequency of plates. Acushnet sets out its allegations relating to this defense with specificity in

its fifth counterclaim, seeking a declaratory judgment of unenforceability as to each of the patents-in-suit. Acushnet incorporates those allegations in this defense by this reference.

COUNTERCLAIMS

Plaintiff-in-counterclaim Acushnet asserts the following counterclaims against defendant-in-counterclaim Callaway:

PARTIES

1. The plaintiff-in-counterclaim, Acushnet, is a Delaware corporation with a principal place of business in Fairhaven, Massachusetts.

2. The defendant-in-counterclaim, Callaway, is a Delaware corporation with a principal place of business in Carlsbad, California.

JURISDICTION AND VENUE

3. Acushnet counterclaims for a declaratory judgment that each of the Asserted Patents is invalid, unenforceable and/or not infringed by any act of Acushnet. These counterclaims arise under the Declaratory Judgment Act, 28 U.S.C. §§ 2201 and 2202, and the United States Patent laws, 35 U.S.C. *et seq*.

4. This Court has subject matter jurisdiction over these counterclaims and Acushnet's patent infringement counterclaims pursuant to 28 U.S.C. §§ 1331, 1338 and 2201.

5. Based on the foregoing allegations, and by virtue of Callaway's commencement of the present action, a justiciable controversy exists and this Court has personal jurisdiction over Callaway.

6. Venue is proper in this court for these counterclaims pursuant to 28 U.S.C. §§ 1391 and 1400, and by virtue of Callaway's commencement of the present action in this Court.

FIRST COUNTERCLAIM
(Declaratory Judgment of Invalidity and Noninfringement)

7. Acushnet repeats the allegations set forth in paragraphs 1 through 6 as if fully set forth herein.

8. Callaway alleges to be the owner by assignment of the Asserted Patents. Callaway has filed a Complaint alleging that Acushnet has infringed and continues to infringe the Asserted Patents. Accordingly, a substantial and continuing justiciable controversy exists between Acushnet and Callaway as to the infringement, validity and enforceability of the Asserted Patents.

9. Acushnet has not infringed and is not infringing the Asserted Patents, either literally or under the doctrine of equivalents, nor is it infringing them pursuant to the reverse doctrine of equivalents.

10. Each of the claims of the Asserted Patents is invalid due to a failure to comply with the requirements of patentability as set forth in Title 35 U.S.C. *et seq*., including, but not limited to, §§ 101, 102, 103 and 112.

SECOND COUNTERCLAIM
(Infringement of U.S. Patent No. 6,960,142)

11. Acushnet repeats the allegations set forth in paragraphs 1 through 6 as if fully set forth herein.

12. Acushnet is the owner by assignment of United States Patent No. 6,960,142 ("the '142 patent"), entitled GOLF CLUB HEAD WITH A HIGH COEFFICIENT OF RESTITUTION, which was duly and legally issued by the United States Patent and Trademark Office to Laurent C. Bissonnette *et al.* on November 1, 2005, a copy of which is attached hereto as Exhibit A.

13. Callaway is infringing and has infringed the '142 patent by making, offering to sell or selling its FT-i, FT-5, X-460, X-460 Tour, Big Bertha Fusion FT-3, Big Bertha 460, Hyper X, and Hyper X Tour golf clubs.

14. Upon information and belief, Callaway has had knowledge of the '142 patent, and its infringement of the '142 patent is willful, wanton and in deliberate disregard of Acushnet's rights under the '142 patent.

15. Acushnet has been irreparably harmed to an extent not yet determined by Callaway's infringement, and will continue to be irreparably harmed in the future unless Callaway is enjoined from its activities by this Court.

THIRD COUNTERCLAIM
(Infringement of U.S. Patent No. 7,041,003)

16. Acushnet repeats the allegations set forth in paragraphs 1 through 6 as if fully set forth herein.

17. Acushnet is the owner by assignment of United States Patent No. 7,041,003 ("the '003 patent"), entitled GOLF CLUB HEAD WITH VARIABLE FLEXURAL STIFFNESS FOR CONTROLLED BALL FLIGHT AND TRAJECTORY, which was duly and legally issued by the United States Patent and trademark Office to Laurent C. Bissonnette *et al.* on May 9, 2006, a copy of which is attached hereto as Exhibit B.

18. Callaway is infringing and has infringed the '003 patent by making, offering to sell or selling its FT-i, FT-5, X-460, X-460 Tour, Big Bertha Fusion FT-3, Big Bertha 460, Hyper X, and Hyper X Tour golf clubs.

19. Upon information and belief, Callaway has had knowledge of the '003 patent, and its infringement of the '003 patent is willful, wanton and in deliberate disregard of Acushnet's rights under the '003 patent.

20. Acushnet has been irreparably harmed to an extent not yet determined by Callaway's infringement, and will continue to be irreparably harmed in the future unless Callaway is enjoined from its activities by this Court.

FOURTH COUNTERCLAIM
(Infringement of U.S. Patent No. 7,140,975)

21. Acushnet repeats the allegations set forth in paragraphs 1 through 6 as if fully set forth herein.

22. Acushnet is the owner by assignment of United States Patent No. 7,140,975 ("the '975 patent"), entitled GOLF CLUB HEAD WITH VARIABLE FLEXURAL STIFFNESS FOR CONTROLLED BALL FLIGHT AND TRAJECTORY, which was duly and legally issued by the United States Patent and Trademark Office to Laurent C. Bissonnette *et al.* on May 12, 2005, a copy of which is attached hereto as Exhibit C.

23. Callaway is infringing and has infringed the '975 patent by making, offering to sell or selling its Hyper X and Hyper X Tour golf clubs.

24. Upon information and belief, Callaway has had knowledge of the '975 patent, and its infringement of the '975 patent is willful, wanton and in deliberate disregard of Acushnet's rights under the '975 patent.

25. Acushnet has been irreparably harmed to an extent not yet determined by Callaway's infringement, and will continue to be irreparably harmed in the future unless Callaway is enjoined from its activities by this Court.

FIFTH COUNTERCLAIM
(Declaratory Judgment of Unenforceability)

Unenforceability of the Callaway patents-in-suit due to inequitable conduct based upon material false statement to the PTO

26. Acushnet repeats the allegations set forth in paragraphs 1 through 6 as if fully set forth herein.

27. Callaway's patents, which name Callaway as the assignee, are unenforceable due to inequitable conduct based upon material false statements in the specification. Specifically, the Callaway patents describe an alleged inventive club with "striking plate flexibility levels greater than found in any current club-head." (*See, e.g.*, '015 patent at col. 10, line 49-col. 11, line 45.) The Callaway patents directly relate flexibility to natural frequency. (*See, e.g.*, '015 patent at col. 2, lines 14-49). Flexibility in the striking plate, as the patent states, [redacted] is the goal of the patents and is measured by natural frequency. (*See id.* at Col. 2, ll. 60-64 (noting that one object of the invention is to increase dynamic flexibility).) According to the Callaway patents, the lower the frequency, the more flexible the striking plate. (*See id.*) The Callaway patents disclose that the alleged inventive club had a natural frequency of 6040 Hz. (*See, e.g.*, '015 patent at col. 11, lines 1-2).

[redacted]

[redacted]

33. Each Callaway patent is unenforceable due to this false material statement knowingly made to the PTO.

Unenforceability of the Callaway patents-in-suit due to inequitable conduct based upon false material statement to the PTO and failure to cite material prior art

34. Acushnet repeats the allegations set forth in paragraphs 1 through 6 as if fully set forth herein.

35. Callaway's patents, which name Callaway as the assignee, are unenforceable due to inequitable conduct based upon further false material statements in the specification and the failure to cite material prior art.

36. Specifically, the Callaway patents state that "currently available driver golf club heads have striking-face natural frequencies greater than 4,500 Hz." ('015, Col. 11, lines 46-48.)

[redacted]

[redacted]

[redacted]

50. Each Callaway patent is unenforceable due to this false material statement and failure to cite material prior art that Callaway had in its possession.

Unenforceability of the Callaway patents-in-suit due to inequitable conduct based upon failure to cite material prior art from a related foreign application

51. Acushnet repeats the allegations set forth in paragraphs 1 through 6 as if fully set forth herein.

52. Callaway's patents, which name Callaway as the assignee, are unenforceable due to inequitable conduct based upon Callaway's failure to cite material prior art from a related foreign application to the PTO.

[redacted]

55. These three Japanese references were highly material to patentability, as evidenced by the fact that one or more of these reference was used to reject claims of related applications in at least two foreign countries.

56. For example, Kubota describes a golf club head with a striking plate having a natural frequency less than 4,000 Hz, where the striking plate is made out of a different material than the body. The Kubota reference was highly material to patentability, as it anticipates many claims of the Callaway patents.

57. Under 37 C.F.R. 1.56, Catania and Lo were under an affirmative duty to inform the PTO of any art raised in the related foreign proceedings. Catania and Lo were obviously aware of their duty, as attorneys of Kosmatka and the assignee, Callaway, to disclose art cited in

related foreign prosecution, as they disclosed a PCT search report during the prosecution of the '579 patent. Kosmatka was aware of his duties under Rule 56, as evidenced by his signature on the Declarations.

58. Despite knowing of their duty, and despite the fact that these three Japanese references were highly material to patentability, neither Catania, Lo, nor Kosmatka disclosed them to the PTO.

[redacted]

60. Catania, Lo, and/or Kosmatka failed to disclose these three Japanese references with an intent to deceive the PTO.

61. Each Callaway patent is unenforceable due to this failure to cite material prior art.

Unenforceability of the Callaway patents-in-suit due to inequitable conduct based upon failure to cite material prior art when filing a CIP application

62. Acushnet repeats the allegations set forth in paragraphs 1 through 6 as if fully set forth herein.

63. Callaway's patents, which name Callaway as the assignee, are unenforceable due to inequitable conduct based Callaway's failure to cite material prior art when filing a continuation-in-part patent application.

64. Specifically, on February 15, 2002, Callaway filed the application that ultimately issued as the second patent, the '692 patent. This application was a continuation-in-part application from the '015 patent because Callaway added subject matter to the application's specification that described a golf club head with a "large volume," for example between 300 and 450 cubic centimeters, to provide a written description for claims with a volume limitation.

65. Because Callaway filed the '692 patent's application as a continuation-in-part, Kosmatka, Catania, Lo, and/or other individuals at Callaway substantively involved in the preparation and/or prosecution of the Callaway's applications had a duty under 37 C.F.R. § 1.56(e) to disclose prior art which became available between the filing date of the prior application (March 14, 2000) and the continuation-in-part application (February 15, 2002).

66. However, these individuals failed to provide any information to the PTO regarding the sale and public use of its own thin-faced, titanium ERC golf club in the United States [redacted]

67. In addition, these individuals failed to provide any information to the PTO regarding the sale and public use of its thin-faced, titanium ERC II golf club in the United States, [redacted]

68. Callaway disclosed and/or sold the ERC and ERC II golf clubs in the United States in 2000, two years before the filing date of the continuation-in-part application.

[redacted]

70. Despite this prior public sale, Callaway continued to pursue claims that covered the ERC and ERC II golf clubs, and other golf clubs available prior to February 15, 2002, and never disclosed that information to the PTO.

[redacted]

[redacted]

72. Despite being aware of the materiality of the ERC and ERC II golf clubs, Kosmatka, Catania, Lo, and/or other individuals at Callaway substantively involved in the preparation and/or prosecution of Callaway's applications failed to disclose any information relating to the ERC and ERC II golf clubs with an intent to deceive the PTO.

73. Each Callaway patent is unenforceable, including through the doctrine of infectious unenforceability, for failure to disclose information relating to the ERC and ERC II golf clubs.

Unenforceability of the Callaway patents-in-suit due to inequitable conduct based upon failure to cite material information

74. Acushnet repeats the allegations set forth in paragraphs 1 through 6 as if fully set forth herein.

75. Callaway's patents, which name Callaway as the assignee, are unenforceable due to inequitable conduct based upon the failure to cite information relating to the Liquid Metal golf club described in the specification.

76. In the specification, Callaway admitted that the commercially-available Liquid Metal golf club head "has a fundamental natural frequency striking plate of 5,850 Hz," which falls between 2,800 and 8,500 Hz.

77. However, Kosmatka, Catania, Lo and/or other individuals at Callaway substantively involved in the preparation and/or prosecution of Callaway's applications pursued claims directed at golf club heads that had striking plate natural frequencies between 2,800 and 8,500 Hz, where the striking plate was composed of a different material than the body (e.g.,

claim 5 of the '015 patent) or where the striking plate was disposed in the "open front" of the body of the golf club head (e.g., claim 21 of the '015 patent).

78. On information and belief, these individuals were aware that the Liquid Metal golf club head had a striking plate that was composed of a different material than the body (like claim 5), and had a striking material that was disposed in the open front of the body of the golf club head (like claim 21). Had the Examiner known this information, the Examiner would not have allowed the claims of the Callaway patents, in particular those directed at golf club heads with striking plate natural frequencies between 2,800 and 8,500 Hz.

79. On information and belief, these individuals failed to provide any information regarding the Liquid Metal golf club head with an intent to deceive the PTO.

80. Each Callaway patent is unenforceable due to the failure to provide any information relating to the Liquid Metal golf club.

Unenforceability of the Callaway patents-in-suit due to inequitable conduct based upon failure to cite material prior art

81. Acushnet repeats the allegations set forth in paragraphs 1 through 6 as if fully set forth herein.

82. Callaway's patents, which name Callaway as the assignee, are unenforceable due to inequitable conduct based upon Callaway's failure to cite information relating to the United States Golf Association's ("USGA's") testing for "spring-like effect."

[redacted]

[redacted]

86. Kosmatka and Callaway's in-house attorneys, including Catania and Lo, knew of the S.H. Johnson article during prosecution of Callaway's applications, because they cited the Science and Golf III: Proceedings of the 1998 World Scientific Congress of Golf reference to the PTO with respect to the prosecution of other Callaway patents. (*See, e.g.*, U.S. Patent No. 6,527,648.)

[redacted]

88. The Yamaguchi patent, U.S. Patent No. 4,928,965, describes a golf club head having the same striking plate natural frequencies as described in Callaway's patents, and anticipates several claims.

[redacted]

[redacted]

90. Information relating to the USGA's testing of titanium plates, the S.H. Johnson article, and the Tangent Plus 10 was material to patentability. The Tangent Plus 10 golf club, in particular, was material to patentability because it has a striking plate natural frequency less than 4,500 Hz, and anticipates many claims of the Callaway patents.

91. On information and belief, Kosmatka, Catania, Lo, and/or other individuals at Callaway substantively involved in the preparation and/or prosecution of Callaway's patent applications did not disclose this information because they intended to deceive the PTO.

92. Each Callaway patent is unenforceable due to the failure to cite this material information to the PTO.

Unenforceability of the Callaway patents-in-suit due to inequitable conduct based upon failure to cite relevant prior art

93. Acushnet repeats the allegations set forth in paragraphs 1 through 6 as if fully set forth herein.

94. Callaway's patents, which name Callaway as the assignee, are unenforceable due to inequitable conduct based upon the failure of Kosmatka, Catania, Lo, and/or other individuals at Callaway substantively involved in the preparation and/or prosecution of Callaway's patent applications to cite to treatises relating to natural frequency of plates.

95. Specifically, Callaway's patents describe the use of mathematical formulas to lower the natural frequency of the striking plate.

[redacted]

[redacted]

97. Each of the false statements and omitted references described in paragraphs 26-96 would have been considered by a reasonable examiner to be material to a determination of allowability of the patent claims, and on information and belief, said statements and omissions were made with intent to deceive the Patent Office.

98. Accordingly, each of the Callaway patents are unenforceable due to inequitable conduct.

99. In addition, each of the Callaway patents are unenforceable based on the doctrine of infectious unenforceability given their immediate and necessary relationship.

WHEREFORE, Acushnet prays for judgment and relief as follows:

A. That Callaway's Complaint be dismissed with prejudice and that Callaway take nothing by way of its Complaint;

B. That this Court enter an Order declaring that Acushnet does not infringe and has not infringed any claim of the '015, '692, '579, '576 or '032 patents;

C. That this Court enter an Order declaring that each and every claim of the '015, '692, '579, '576 or '032 patents is invalid and/or unenforceable;

D. That this Court enter an Order declaring that Callaway infringes the '142 patent;

E. That this Court enter an Order declaring that Callaway infringes the '003 patent;

F. That this Court enter an Order declaring that Callaway infringes the '975 patent;

G. That this Court permanently enjoin Callaway, its officers, agents, employees, representatives, successors and assigns, and any others acting in concert with it, from infringing the '142, '003, and '975 patents;

H. That this Court award Acushnet adequate damages resulting from Callaway's infringement;

I. That this Court award Acushnet treble their damages due to Callaway's willful infringement;

J. That this Court declare this to be an exceptional case within the meaning of 35 U.S.C. § 285;

K. That this Court award Acushnet their costs in this action, together with reasonable attorney's fee and pre-judgment interest; and

L. That this Court grant Acushnet such other relief as it deems just and proper.

JURY DEMAND

Acushnet demands a trial by jury on all issues so triable.

POTTER ANDERSON & CORROON LLP

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IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

CERTIFICATE OF SERVICE

I, David E. Moore, hereby certify that on July 24, 2008, the attached document was electronically filed with the Clerk of the Court using CM/ECF which will send notification to the registered attorney(s) of record that the document has been filed and is available for viewing and downloading.

I further certify that on July 24, 2008, the attached document was Electronically Mailed to the following person(s):

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804408 / 31957

EXHIBIT A

US006960142B2

(12) **United States Patent**
Bissonnette et al.

(10) **Patent No.: US 6,960,142 B2**
(45) **Date of Patent: *Nov. 1, 2005**

(54) **GOLF CLUB HEAD WITH A HIGH COEFFICIENT OF RESTITUTION**

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(73) Assignee: **Acushnet Company**, Fairhaven, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **10/425,881**

(22) Filed: **Apr. 30, 2003**

(65) **Prior Publication Data**

US 2003/0199334 A1 Oct. 23, 2003

Related U.S. Application Data

(63) Continuation of application No. 09/551,771, filed on Apr. 18, 2000, now Pat. No. 6,605,007.

(51) **Int. Cl.**[7] **A63B 53/04**
(52) **U.S. Cl.** **473/329**; 473/345; 473/349
(58) **Field of Search** 473/290, 291, 473/324, 329, 332, 342, 345, 346, 349, 350

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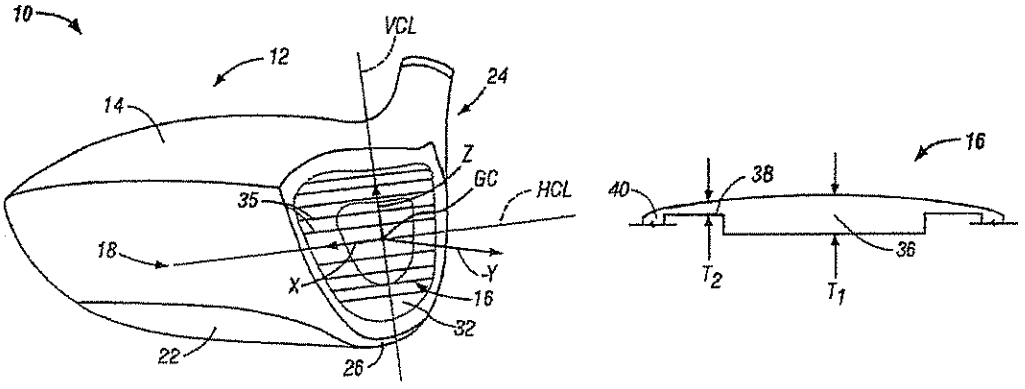
Primary Examiner—Sebastiano Passaniti
(74) *Attorney, Agent, or Firm*—Swindler Berlin LLP

(57) **ABSTRACT**

The present invention relates to a golf club head provided with a face and a body. The face has a central zone and a intermediate zone adjacent and surrounding the central zone. The central zone has a first flexural stiffness and the intermediate zone has a second flexural stiffness. The club head face is configured and dimensioned such that the first flexural stiffness is significantly greater than the second flexural stiffness such that upon ball impact with the face, the intermediate zone exhibits substantial deformation so that the central zone moves into the club head. At the same time, the central zone exhibits minimal deformation so that it moves into and out of the club head as a unit. Furthermore, the face exhibits a high coefficient of restitution.

28 Claims, 10 Drawing Sheets



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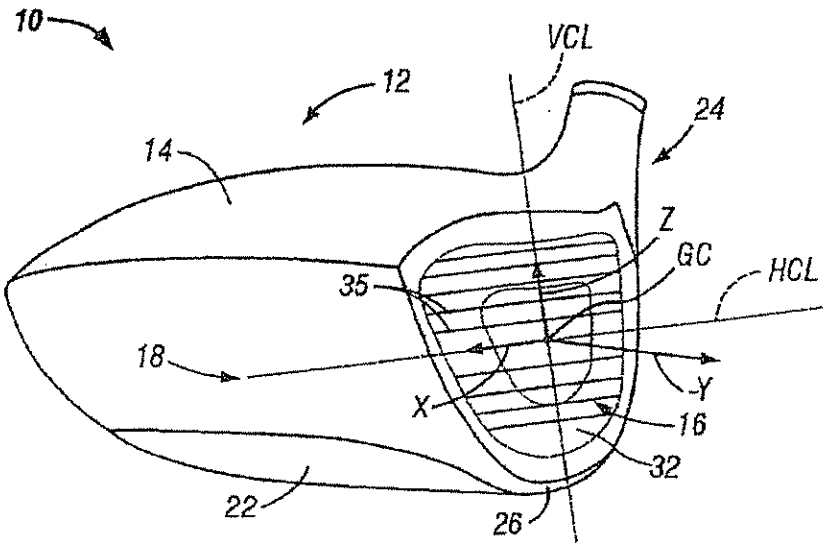

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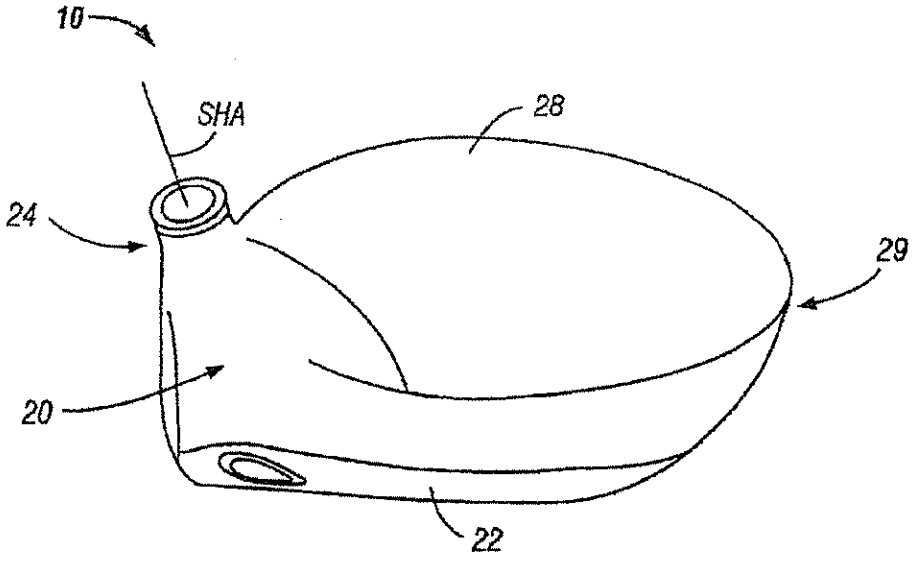
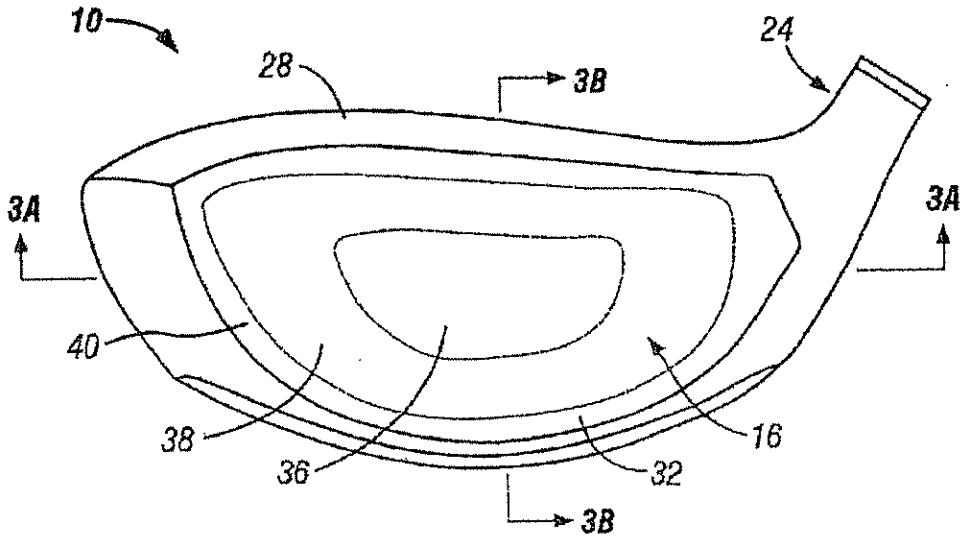


FIG. 2



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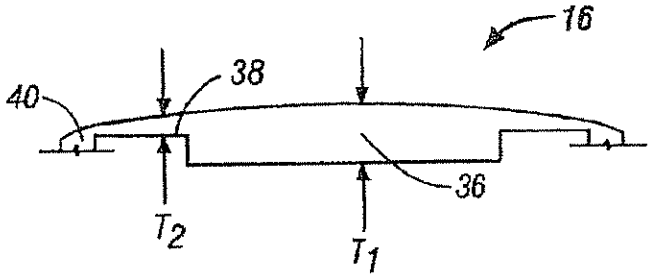
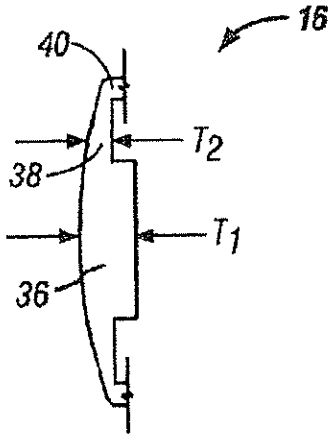


FIG 3A



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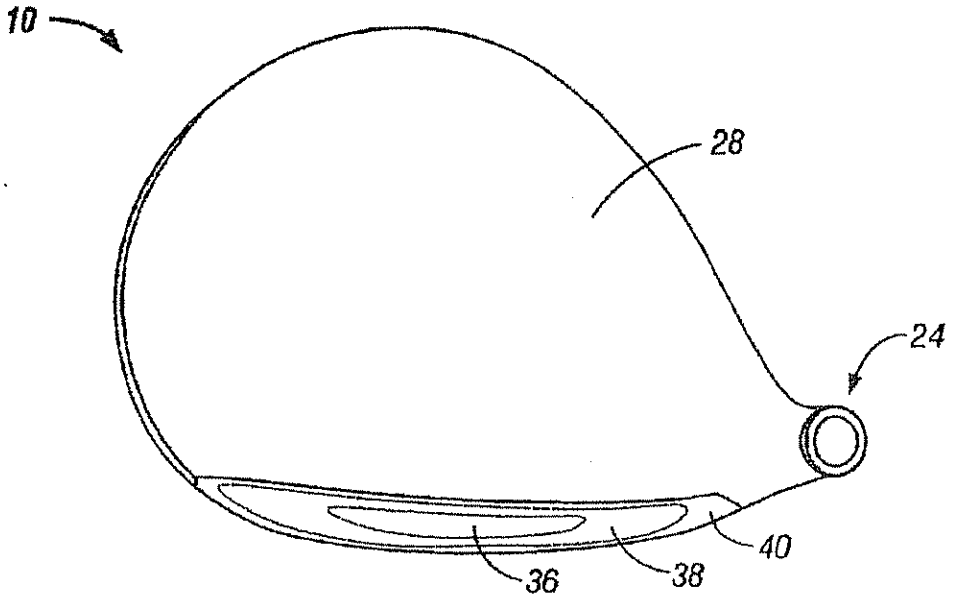

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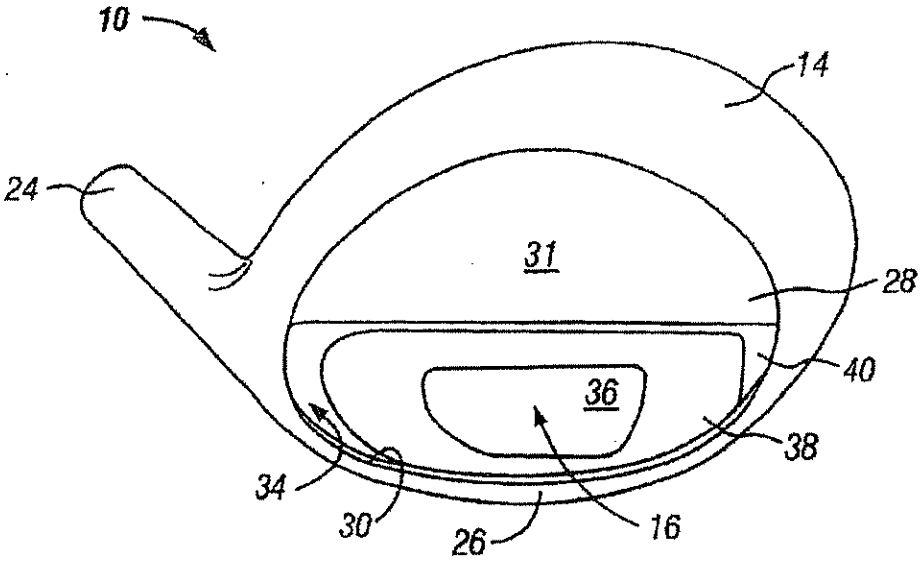

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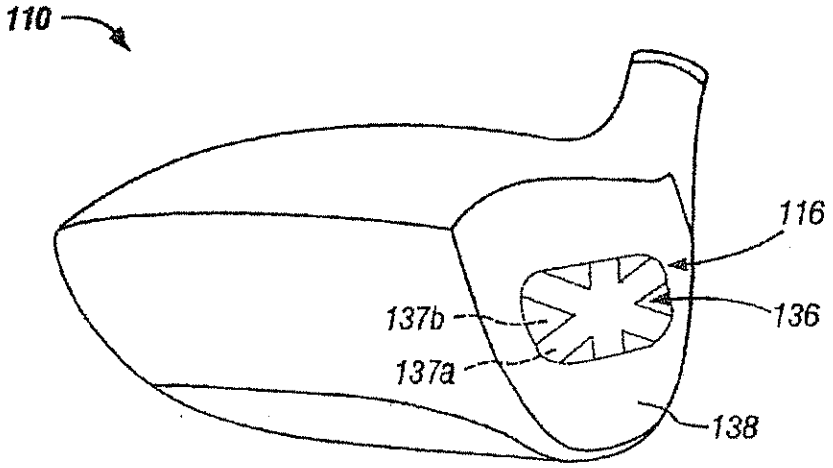

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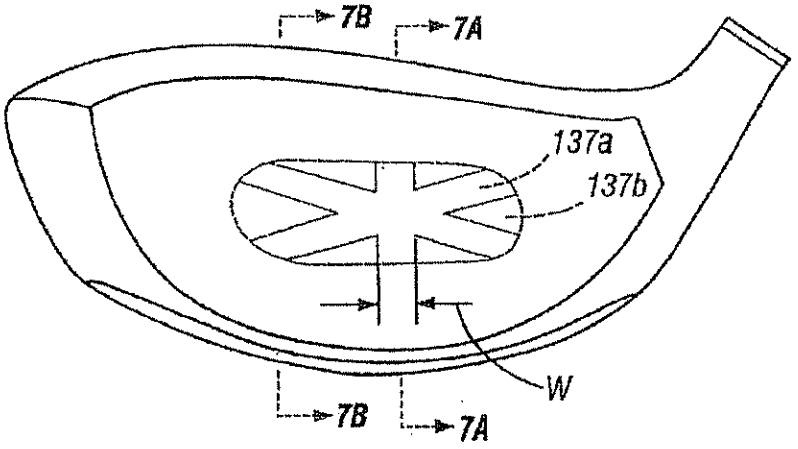

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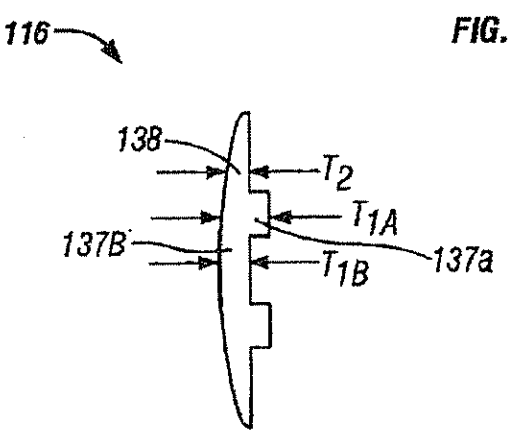

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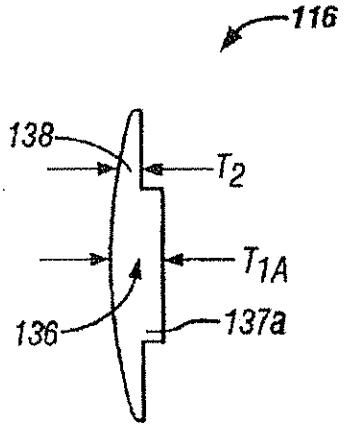
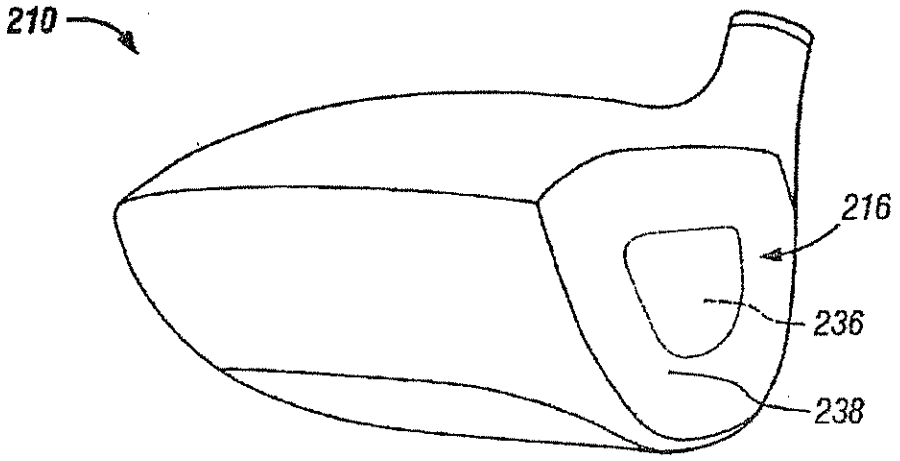


FIG. 7B



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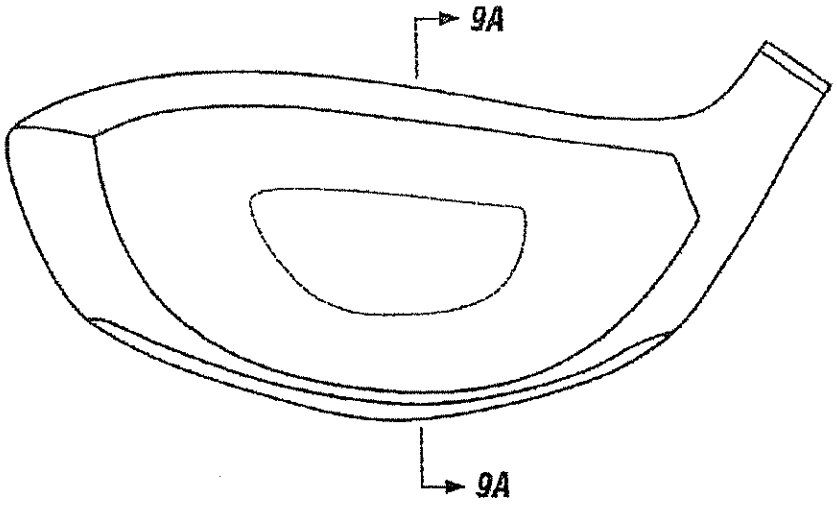

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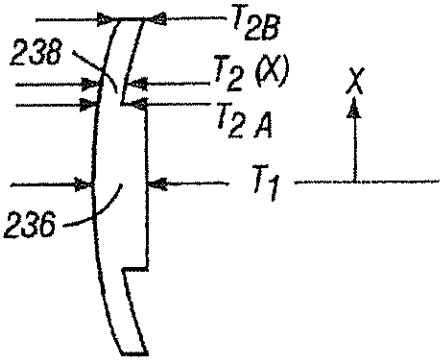
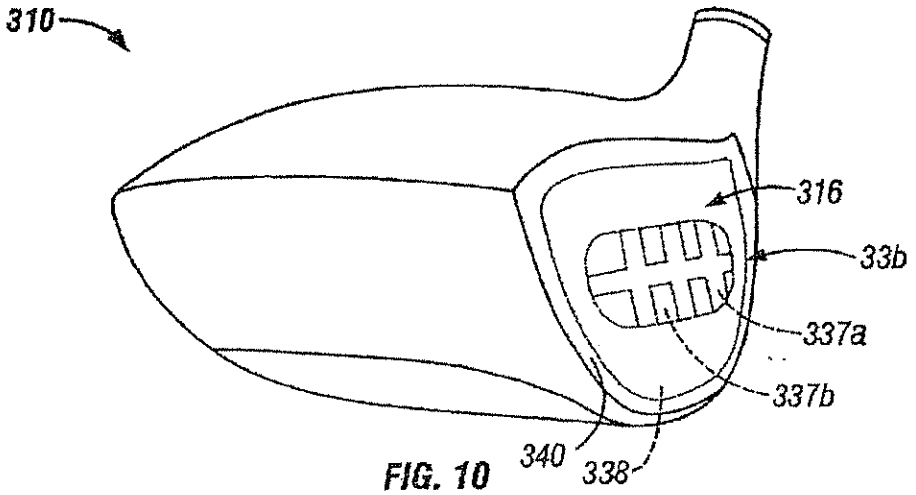


FIG. 9A



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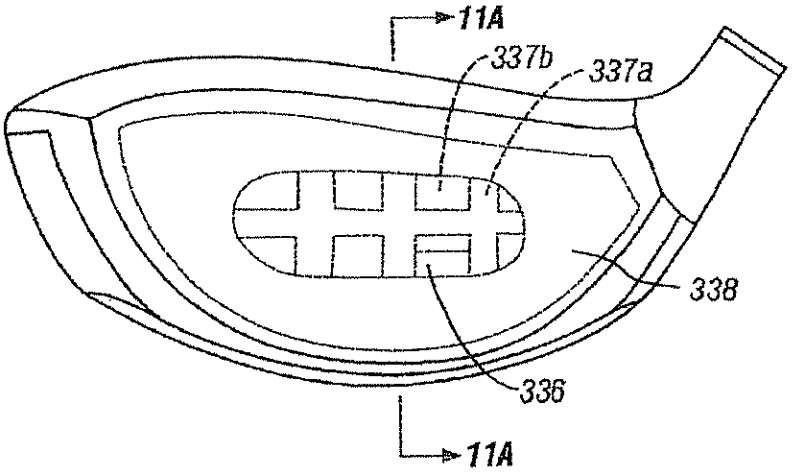

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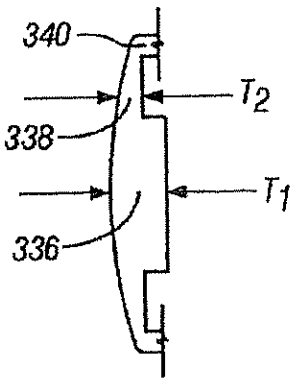

FIG. 11A

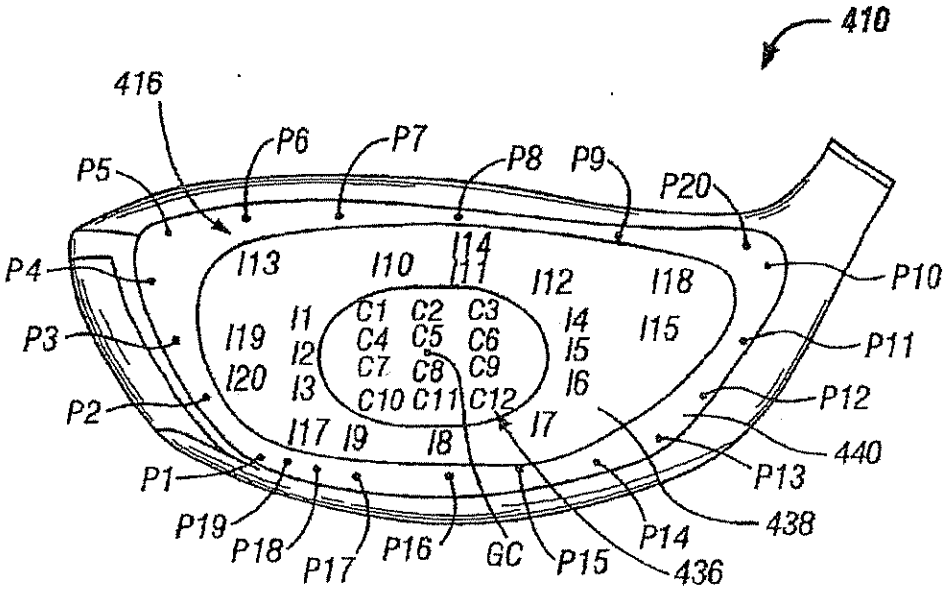
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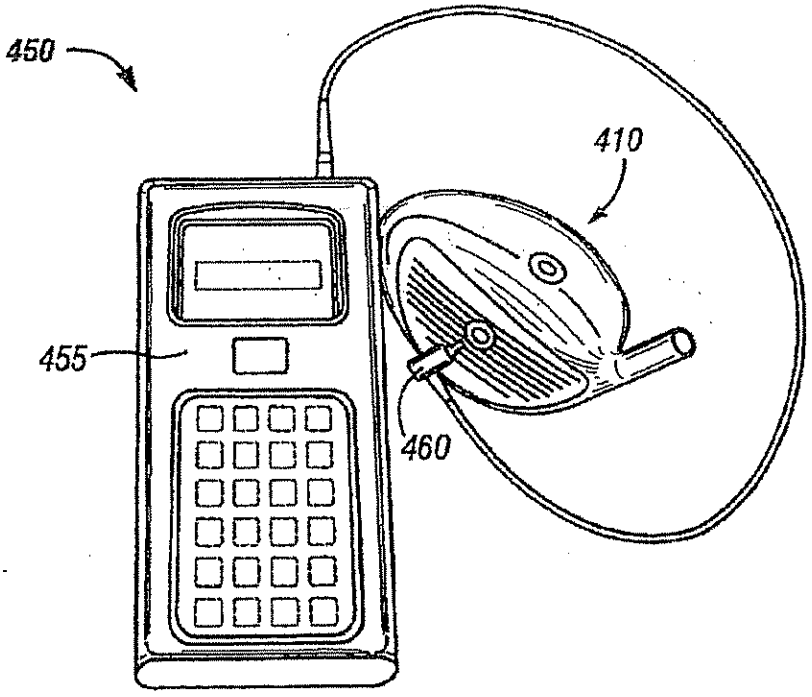
FIG. 12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460

FIG. 13

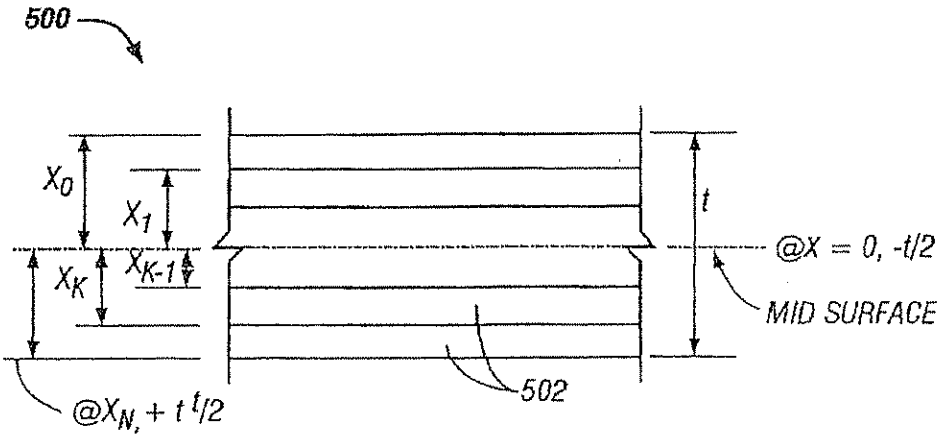

FIG. 14

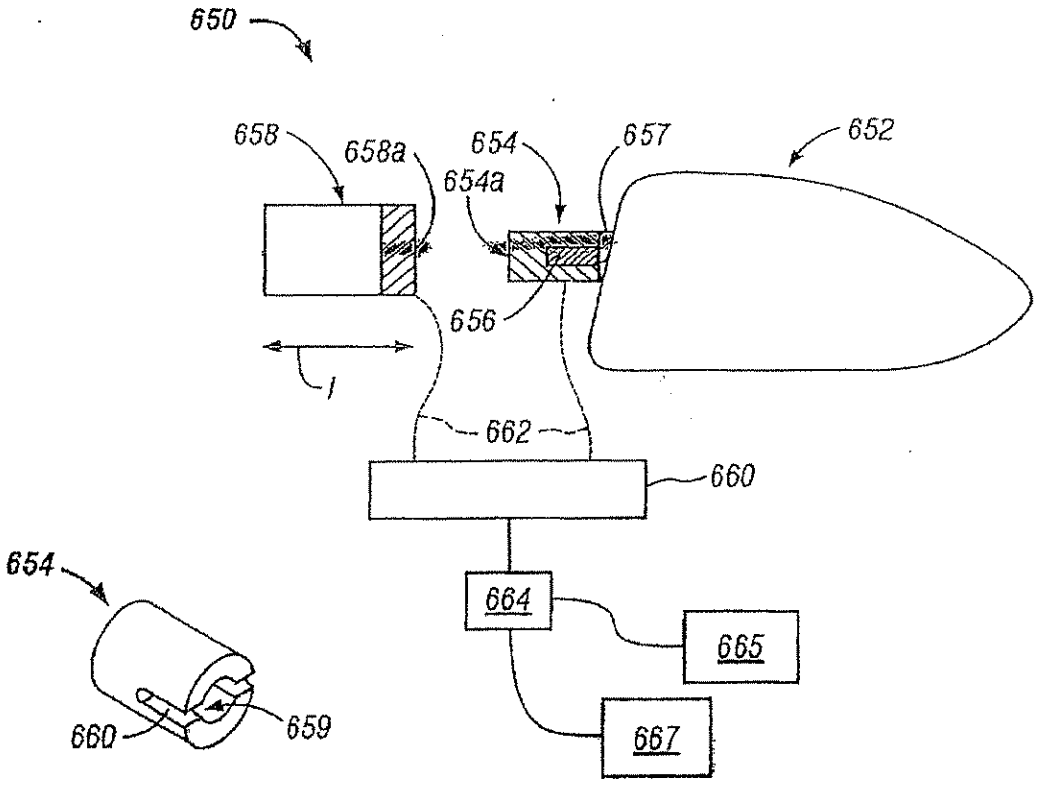

FIG. 15A FIG. 15

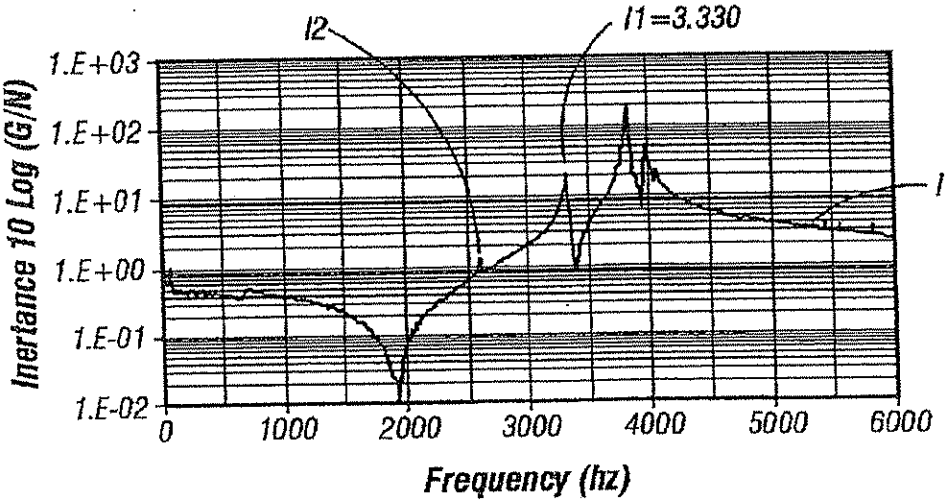
I2
I1=3.330
I
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
Inertance 10 Log (G/N)
0
1000
2000
3000
4000
5000
6000
Frequency (hz)

FIG. 16

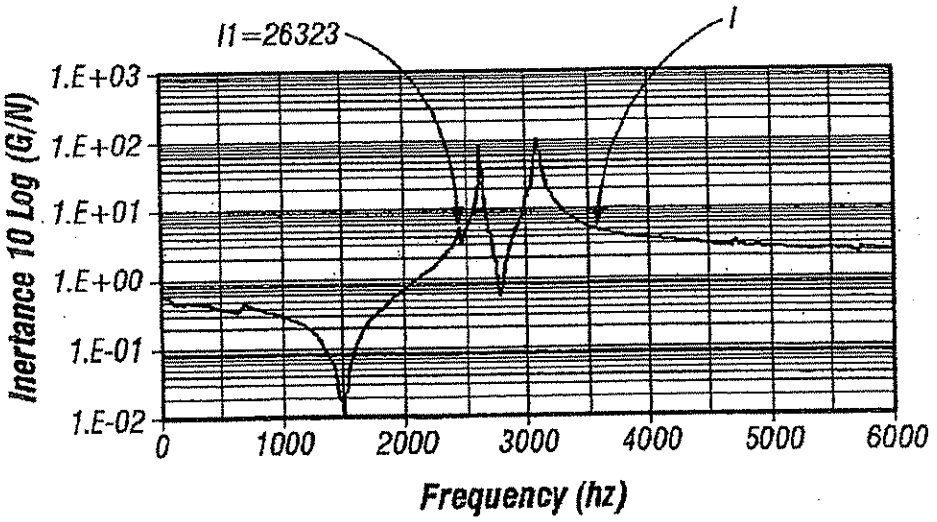
I1=26323
I
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
Inertance 10 Log (G/N)
0
1000
2000
3000
4000
5000
6000
Frequency (hz)

FIG. 17

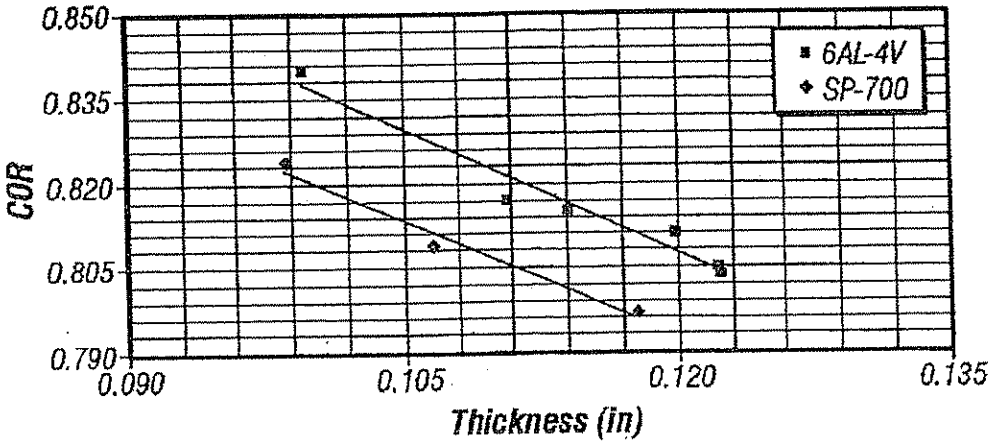
0.850
0.835
0.820
0.805
0.790
COR
0.090
0.105
0.120
0.135
Thickness (in)
6AL-4V
SP-700

FIG. 18

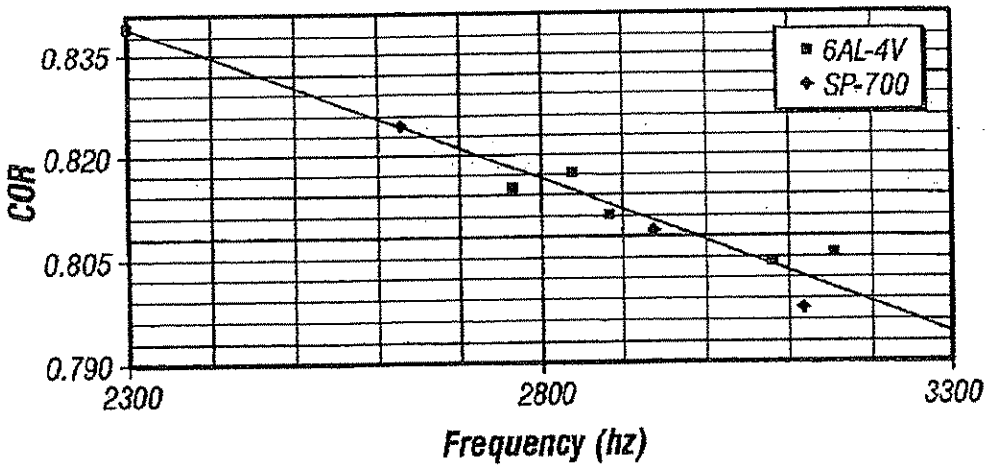
0.835
0.820
0.805
0.790
COR
2300
2800
3300
Frequency (hz)
6AL-4V
SP-700

FIG. 19

GOLF CLUB HEAD WITH A HIGH COEFFICIENT OF RESTITUTION

This application is a continuation of U.S. patent application Ser. No. 09/551,771, filed Apr. 18, 2000, now U.S. Pat. No. 6,605,007, which is incorporated in its entirety by reference herein.

FIELD OF THE INVENTION

The invention is an improved golf club head. More particularly, the invention is a golf club head with an improved striking face having discrete zones with varying flexural stiffness, improved accuracy, and a high coefficient of restitution.

BACKGROUND OF THE INVENTION

The complexities of golf club design are well-known. The choice of specifications for each component of the club (i.e., the club head, shaft, hosel, grip, and subcomponents thereof) directly impacts the performance of the club. Thus, by varying the design specifications, a golf club can be tailored to have desirable performance characteristics.

The design of club heads has long been studied. Among the more prominent considerations in club head design are loft, lie, face angle, horizontal face bulge, vertical face roll, face progression, face size, sole curvature, center of gravity, material selection, and overall head weight. While this basic set of criteria is generally the focus of golf club engineering, several other design aspects must also be addressed. The interior design of the club head may be tailored to achieve particular characteristics, such as by including hosel or shaft attachment means, perimeter weighting on the face or body of the club head, and fillers within hollow club heads.

The designs for golf club heads must also be strong enough to withstand the impact forces that occur during collision between the head and the ball. The loading that occurs during this transient event can cause an acceleration to the golf ball that is four orders of magnitude greater than that of gravity. Thus, the club face and body should be designed to resist permanent deformation or catastrophic failure, by material yield or fracture.

It is not unusual for club heads of prior art hollow metal woods, produced from titanium, to have a uniform face thickness exceeding 0.15 inches. This thickness has been required to ensure structural integrity of the club head during impact.

Players generally seek a wood and golf ball combination that delivers maximum distance and landing accuracy. The distance a ball travels after impact is dictated by the magnitude and direction of the ball's translational velocity and the magnitude and direction of the ball's rotational velocity or spin. Environmental conditions, including atmospheric pressure, humidity, temperature, and wind speed further influence ball flight. However, these environmental effects are beyond the control of the golf equipment manufacturer. Golf ball landing accuracy is driven by a number of factors as well. Some of these can be attributed to club head design. Primarily, of concern here are center of gravity and club face flexibility.

Golf ball distance is a function of the total kinetic energy imparted to the ball during impact with the club head, neglecting environmental effects. During impact, kinetic energy is transferred from the club and stored as elastic strain energy in the club head and the ball. After impact, the stored elastic energy is transformed back into kinetic energy

in the form of translational and rotational velocity of the ball as well as the club. Since the collision is not perfectly elastic, a portion of energy is dissipated in club head vibration and viscoelastic relaxation of the ball. Viscoelastic relaxation is a material property of the polymeric materials used in all manufactured golf balls.

The United States Golf Association (USGA), the governing body for the rules of golf in the United States, has specifications for the performance of golf balls. These performance specifications dictate the size and weight of a golf ball that conforms to the USGA. Furthermore, there are USGA rules which limit the golf ball velocity after a prescribed impact to 250 feet per second ±5%. To achieve greater golf ball distance, ball velocity after impact must be maximized while remaining within these guidelines. Viscoelastic relaxation of the ball is a parasitic energy source, which is dependent upon the rate of deformation. To minimize this effect, the rate of deformation must reduced. This may be accomplished by allowing more club face deformation during impact. Since metallic deformation maybe purely elastic, the strain energy stored in the club face is returned to the ball after impact thereby increasing the ball's outbound velocity after impact.

A variety of techniques may be utilized to vary the allowable deformation of the club face. For example, uniform face thinning, thinned faces with ribbed stiffeners and a varied thickness on the face profile are three possibilities. Any design must have sufficient structural integrity to withstand impact without permanent deformation of the club face.

In general, prior art club heads exhibit large variations in the coefficient of restitution (COR) magnitude with impact location on the face of the club. Furthermore, accuracy of those prior art clubs are highly dependent on this impact location.

Thus, there is a need for a golf club with a face that maximizes golf ball distance while maintaining accuracy due to a reduced sensitivity to face impact location. Furthermore, it would be desirable for the improved club design to minimize the dissipation of spurious energy modes of structural vibration of the club to further maximize efficient energy transfer after impact.

SUMMARY OF THE INVENTION

The present invention relates to a golf club head adapted for attachment to a shaft. The head includes a face and a body. The face is configured and dimensioned so that it includes a central portion and an adjacent surrounding intermediate portion. The central portion is rigid and the intermediate portion is relatively flexible so that upon ball impact, the intermediate portion of the face deforms to provide high ball velocity, while the central portion is substantially undeformed so that the ball flies on-target. Thus, upon ball impact the deformation of the intermediate portion allows the central region to move into and out of the club head as a unit. As a result, the head exhibits a coefficient of restitution greater than 0.81.

The above is accomplished by providing the central portion with a first flexural stiffness and the intermediate portion with a second flexural stiffness. Flexural stiffness is defined as the portion's Elastic modulus (E) times the portion's thickness (t) cubed or Et^3. The first flexural stiffness is substantially different from the second flexural stiffness. As a result, upon ball impact, the intermediate portion exhibits substantial deformation so that the central portion moves into the club head, and the central portion exhibits minimal deformation.

In one embodiment, the first flexural stiffness is at least three times the second flexural stiffness. In other embodiments, the first flexural stiffness is six to twelve times the second flexural stiffness.

More preferably, the first flexural stiffness is greater than 25,000 lb-in. Most preferably, the first flexural stiffness is greater than 55,000 lb-in. Preferably, the second flexural stiffness is less than 16,000 lb-in. More preferably, the second flexural stiffness is less than 10,000 lb-in.

Since the flexural stiffness is a function of material and thickness, the following techniques can be used to achieve the substantial difference between the first and second flexural stiffnesses: 1) different materials can be used for each portion, 2) different thicknesses can be used for each portion, or 3) different materials and thicknesses can be used for each portion. For example, in one embodiment, the thickness of the central portion is greater than the thickness of the intermediate portion and the material for both portions is titanium.

The golf club head further includes a perimeter portion disposed between the intermediate portion and the body. In one embodiment, the perimeter portion has a third flexural stiffness that is at least two times greater than the second flexural stiffness. The area of the perimeter portion preferably comprises less than 30% of the total area of the club head face.

In an alternative embodiment, a golf club head includes a shell that defines an inner cavity and a face. The face defines a face area and includes a first portion in the center and a second portion adjacent thereto. The first portion has a first thickness and defines a first area. The second portion has a second thickness. The first area is between about 15% and about 60% of the total face area, and the first thickness is greater than the second thickness. More preferably, the first area is between about 20% and 50% of the face area.

In the club heads discussed above, the first, second, and third portions can have various shapes, such as the shape of the face or an elliptical shape. Furthermore, the club head inner cavities can have a volume greater than about 250 cubic centimeters, and more preferably a volume greater than about 275 cubic centimeters. It is recommended that the face of the club head have a loft of greater than about 13°.

In addition, the central, intermediate, and perimeter portions can each have variable thicknesses. One feature of the present invention is specifically locating the center of gravity of the club head with respect to a first, second and third axes. The shell further includes a top portion and a spaced sole plate, a heel portion and a spaced toe portion, and a rear spaced from the face. The first axis extends between the top portion and the sole plate. The second axis extends between the heel portion and the toe portion. The third axis extends between the face and the rear portion. The axes meet at the geometric center of the face and the center of gravity is defined with respect to the geometric center of the face. The center of gravity is preferably toward the middle of the second axis and on the third axis at or below the first axis such that the center of gravity is behind the center of the face or lower. Preferably, the center of gravity is on a point of the third axis within the central portion. In one embodiment, the center of gravity is spaced from the geometric center along the first axis by a first distance of at least about 0.1". More preferably, the center of gravity is spaced from the geometric center along the first axis toward the sole plate, wherein the first distance is at least about 0.15". In another embodiment, the center of gravity is spaced a second distance from the geometric center along the second axis, wherein the second distance is less than about 0.02". In addition, the center of gravity is spaced a third distance from the geometric center along the third axis toward the rear portion, wherein the third distance is less than about 1.25".

The present invention is also directed to a golf club head adapted for attachment to a shaft that comprises a face. The face includes a total face area and first primary resonant frequency, which is less than about 2900 Hz. The face further includes a central zone that includes a geometric center of the face, and an intermediate zone disposed adjacent the central zone. The central zone has a first flexural stiffness and a central zone area that is at least 15% of the total face area. The intermediate zone has a second flexural stiffness. The first flexural stiffness is at least 25,000 lb-in and greater than the second flexural stiffness.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred features of the present invention are disclosed in the accompanying drawings, wherein similar reference characters denote similar elements throughout the several views, and wherein:

FIG. 1 is a toe side, front, perspective view of a first embodiment of a golf club head of the present invention;

FIG. 2 is a heel side, rear, perspective view of the golf club head of FIG. 1;

FIG. 3 is a front, elevational view of the golf club head of FIG. 1;

FIG. 3A is a cross-sectional view of the face of the golf club head of FIG. 3 along line 3A—3A;

FIG. 3B shows a cross-sectional view the face of the golf club head of FIG. 3 along line 3B—3B;

FIG. 4 is a top view of the golf club head of FIG. 1;

FIG. 5 is a bottom, perspective view of the golf club head of FIG. 1;

FIG. 6 is a toe side, front, perspective view of a second embodiment of a golf club head of the present invention;

FIG. 7 is a front, elevational view of the golf club head of FIG. 6;

FIG. 7A is a cross-sectional view of the face of the golf club head of FIG. 7 along line 7A—7A;

FIG. 7B shows a cross-sectional view the face of the golf club head of FIG. 7 along line 7B—7B;

FIG. 8 is a toe side, front, perspective view of a third embodiment of a golf club head of the present invention;

FIG. 9 is a front, elevational view of the golf club head of FIG. 8;

FIG. 9A is a cross-sectional view of the face of the golf club head of FIG. 9 along line 9A—9A;

FIG. 10 is a toe side, front, perspective view of a fourth embodiment of a golf club head of the present invention;

FIG. 11 is a front, elevational view of the golf club head of FIG. 10;

FIG. 11A is a cross-sectional view of the face of the golf club head of FIG. 11 along line 11A—11A;

FIG. 12 is an enlarged, front view of a golf club head with ultrasonic thickness measurement locations indicated;

FIG. 13 is a schematic representation of the apparatus for taking an ultrasonic thickness measurement on the face of a club head;

FIG. 14 is an enlarged, elevational view of a portion of the face of a laminated golf club head of the present invention;

FIG. 15 is a schematic representation of a testing apparatus for obtaining frequency response data from a club head;

FIG. 15A is a perspective view of an attached mass for use with the testing apparatus of FIG. 15;

FIG. 16 is a graph of inertance versus frequency for a conventional club head;

FIG. 17 is a graph of inertance versus frequency for the inventive club head;

FIG. 18 is a graph of COR versus face thickness for two alternative titanium alloys; and

FIG. 19, is a graph of COR versus first resonant frequency for two alternative titanium alloys.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIGS. 1–5, a first embodiment of a golf club head **10** of the present invention is shown. Club head **10** includes shell **12** with body **14**, face **16**, toe portion **18**, heel portion **20**, sole plate **22**, hosel **24**, bottom portion **26**, crown portion **28**, and rear portion **29**. The sole plate **22** fits in a recess **30** (as shown in FIG. 5) in the bottom portion **26** of body **14**. The shell **12** and sole plate **22** create an inner cavity **31** (as shown in FIG. 5). The face **16** has an exterior surface **32** and an interior surface **34**. The exterior surface **32** may optionally have grooves **35**.

A golf club shaft (not shown) is attached at hosel **24** and is disposed along a shaft axis SHA. The hosel may extend to the bottom of the club head, may terminate at a location between the top and bottom portions of the head, or the hosel can terminate flush with the top portion and extend into the cavity in the head.

Inner cavity **31** of club head **10** may be empty, or alternatively may be filled with a foam or other low specific gravity material. It is recommended that the inner cavity **31** has a volume greater than 250 cubic centimeters, and more preferably greater than 275 cubic centimeters. Preferably, the mass of the inventive club head is greater than 150 grams but less than 220 grams.

Referring to FIGS. 3–3B, the face **16** includes a central zone or portion **36**, an intermediate zone or surrounding portion **38** adjacent the central zone **36**, and a perimeter zone or outer portion **40**. The central zone **36** is surrounded by the intermediate zone **38** and the perimeter zone **40** surrounds the intermediate zone **38**. The perimeter zone **40** is the zone between the intermediate zone **38** and crown portion **28**. In the following specification and claims, the central zone **36** is a contiguous zone centrally located on the face **16** and containing a geometric center GC of the face.

The zone **36**, **38** and **40** have a shape that is the similar to the shape of the face **16** only with a smaller area, as discussed in detail below. The central zone **36** has a first thickness t_1. The intermediate zone **38** has a second thickness t_2. The first thickness t_1 is greater than the second thickness t_2. Typically, when the club head is cast, the perimeter zone **40** will be thicker than the intermediate zone **38**. However, the present invention is not limited to this configuration. Preferably, the first thickness t_1 is equal to about one and a half (1.5) times the thickness t_2 to about four (4) times the thickness t_2 of the intermediate zone **38** or surrounding portion.

The thickness relationships between the zones **36**, **38**, and **40** are provided so that a predetermined relationship exists between flexural stiffness exhibited by each of the zones. Flexural stiffness (FS) is defined by the following formula:

$$FS=E*t^3$$

where,

E=the Elastic Modulus of the material; and

t=the thickness of the material.

The central zone **36** has a first flexural stiffness FS_1. The intermediate zone **38** has a second flexural stiffness FS_2. The perimeter zone **40** has a third flexural stiffness FS_3. The predetermined relationship between the portions is that the first flexural stiffness FS_1 is substantially greater than the second flexural stiffness FS_2, and optionally the third flexural stiffness FS_3 is substantially greater than the second flexural stiffness FS_2. Preferably, the first flexural stiffness FS_1 is at least three times greater than the second flexural stiffness FS_2. As a ratio the following relationship must be satisfied

$$\frac{FS_1}{FS_2} \geq 3.$$

This expression means the ratio of the central zone flexural stiffness FS_1 over the intermediate zone flexural stiffness FS_2 is equal to or greater than 3.0. When the above ratio of flexural stiffnesses is less than three the central zone sustains excessive deformation during impact and accuracy of the club is diminished. More preferably, the first flexural stiffness FS_1 is at least six to twelve times greater than the second flexural stiffness FS_2. Most preferably, the first flexural stiffness FS_1 is about eight times greater than the second flexural stiffness FS_2.

Preferably, the third flexural stiffness FS_3 is at least two times greater than the second flexural stiffness FS_2. Thus, the following relationship must be satisfied:

$$\frac{FS_3}{FS_2} \geq 2.$$

In club head **10** (as shown in FIG. 3), the above flexural stiffness relationships are achieved by selecting a certain material with a particular Elastic modulus and varying the thickness of the zones. In another embodiment, the flexural stiffness relationships can be achieved by varying the materials of the zones with respect to one another so that the zones have different Elastic moduli and the thickness is changed accordingly. Thus, the thickness of the portions can be the same or different depending on the Elastic modulus of the material of each portion. It is also possible to obtain the required flexural stiffness ratio through the use of structural ribs, reinforcing plates, and thickness parameters.

Quantitatively, it is preferred that the first flexural stiffness FS_1 is greater than 20,000 lb-in. When the first flexural stiffness is less than 20,000 lb-in excessive deformation of the central region can occur during impact and accuracy is diminished. More preferably, the first flexural stiffness FS_1 is greater than 55,000 lb-in. Preferably, the second flexural stiffness FS_2 is less than 16,000 lb-in. When the second flexural stiffness is greater than 18,000 lb-in the COR the resultant ball velocity is reduced. More preferably, the second flexural stiffness FS_2 is less than 10,000 lb-in and, most preferably, less than 7,000 lb-in.

Referring to FIG. **3**, it is recommended that central portion **36** has a first area that is between about 15% and

about 60% of the exterior surface area **32** or face area. The percentage of face area is computed by dividing the area of each zone **36**, **38**, or **40** by the total face area of exterior surface **32**. It should be noted that the total face area of the exterior surface **32** is equivalent to the sum of areas of the zones **36**, **38**, and **40**. In a preferred embodiment, the central zone first area is greater than about 15% and less than about 60% of the total face area. When the central zone **36** is less than 15% of the total face area, then accuracy can be diminished. When central portion **36** is greater than 60% of the face area **32**, then COR can be diminished.

Referring again to FIG. **1**, the club head **10** is further formed so that a center of gravity of the club head has a predetermined relationship with respect to a Cartesian Coordinate System with a center located on the exterior surface and coincident with the geometric center GC of the face **16**. The face includes a vertical centerline CL and a horizontal centerline HCl perpendicular thereto. The geometric face center GC is at the intersection of these centerlines CL and HCl. Preferably, the geometric center of the central zone **36** is coincident with the club face geometric center GC.

The Cartesian Coordinate System is defined when the club head is resting on a flat surface (i.e., at its natural loft) and includes three axes. A vertical or Z-axis is coincident with a gravity vector, g, that acts on the club head. A first direction of the club head extends along the verticle or Z-axis between the crown portion **28** and the sole plate **22**. The positive Z-direction is toward the crown portion **28**. A horizontal or X-axis is perpendicular to the z-axis. A second direction of the club head extends along the X-axis between heel portion **20** (as shown in FIG. 2) and toe portion **18**. The positive X-direction is toward the toe portion **20**. A Y-axis is perpendicular to both the Z-axis and the X-axis. A third direction of the club head extends along the Y-axis between the face **16** and the rear portion **29**. The positive Y-direction is toward the rear portion **29**.

Referring to FIG. **1**, the location of the center of gravity is defined by coordinates for the center of gravity CG_z, CG_y, and CG_x with respect to the Z, X, and Y axes, respectively. In the vertical direction along the Z-axis, the center of gravity coordinate is designated CG_z and is spaced a first distance D1 from the geometric face center G along the Z-axis. The first distance D1 is at least about −0.1 inches, and more preferably the first distance D1 is at least about −0.15 inches so that the center of gravity in the vertical direction is below the geometric center GC.

In the horizontal direction along the X-axis, the center of gravity coordinate is designated CG_x, and is spaced a second distance D2 from the geometric face center GC. The second distance D2 is less than about 0.02 inches and greater than −0.02 inches so that the center of gravity in the horizontal direction is spaced from the center GG by no further than the magnitude of distance D2.

Referring to FIG. **1**, along the Y-axis, the center of gravity coordinate is designated CG_y, and is spaced a third distance D3 from the geometric face center GC preferably toward the rear portion **29**. The center of gravity CG_y in the third direction is spaced from the center GC toward the heel portion **29** by no further than the magnitude of the third distance D3. The third distance D3 is preferably equal to or less than about 1.25 inches and, more preferably, less than about 1 inch.

EXAMPLES

These and other aspects of the present invention may be more fully understood with reference to the following non-limiting examples, which are merely illustrative of embodiments of the present invention golf club head, and are not to be construed as limiting the invention, the scope of which is defined by the appended claims.

TABLE 1

FLEXURAL STIFFNESS INFORMATION

Parameter	Comparative Example 1	Comparative Example 2	Comparative Example 3	Inventive Example
Thickness of Center Zone (inches)	0.115	0.130	0.095	0.150
Thickness of First Intermediate Zone (inches)	0.115	0.100	0.098	0.075
Thickness of Second Intermediate Zone (inches)	0.115	0.080	0.100	0.75
Thickness of Perimeter Portion (inches)	0.115	0.150	0.120	0.120
E of All Portions (psi)	1.65E+0.7	1.65E+0.7	1.65E+0.7	1.65E+0.7
FS of Center Portion (lb-in)	25094	36251	14147	55688
FS of First Intermediate zone (lb-in)	25094	16500	15530	6961
FS of Second Intermediate Zone (lb-in)	25094	8448	16500	6961
FS of Perimeter Zone (lb-in)	25094	55688	28512	28512
FS_1/FS_2	1.0	2.2	0.9	8.0
FS_3/FS_2	1.0	3.4	1.8	4.1

Comparative Examples 1–3 are club heads configured and dimensioned as indicated above with materials so that the zones have certain values. As a result, the ratio of the central zone flexural stiffness and adjacent intermediate zone flexural stiffness for the Comparative Examples are 1.0, 2.2, and 0.9. These ratios do not satisfy the relationship that the central zone flexural stiffness is at least three times the adjacent intermediate zone flexural stiffness. On the other hand, the Inventive Example is configured and dimensioned of a material so that the ratio of central zone flexural stiffness to the adjacent intermediate portion flexural stiffness is about 8. In the examples above, the intermediate zone is defined by a first intermediate zone adjacent the central zone and a second intermediate zone adjacent the first intermediate zone. The perimeter zone is adjacent the intermediate zone(s).

Comparative Examples 1 and 3 have a ratio of perimeter zone flexural stiffness FS_3 to adjacent intermediate zone flexural stiffness FS_2 of 1.0 and 1.8. These ratios do not satisfy the relationship that perimeter zone flexural stiffness is at least twice the intermediate zone flexural stiffness. Comparative Example 2 and the Inventive Example satisfy such a ratio with values of about 3.4 and 4.1, respectively.

TABLE 2

CENTER OF GRAVITY INFORMATION

Parameter	Comparative Example 1	Comparative Example 2	Comparative Example 3	Inventive Example
CG_z Location (inches)[1]	0.074	0.074	0.074	−0.120

TABLE 2-continued

CENTER OF GRAVITY INFORMATION

Parameter	Comparative Example 1	Comparative Example 2	Comparative Example 3	Inventive Example
CG_x Location (inches)[2]	0.133	0.137	0.137	−0.001
CG_y Location (inches)[3]	1.159	1.159	1.182	0.991

[1]Positive$_z$ is above the GC
[2]Positive$_x$ is toward the toe from GC
[3]Positive$_y$ is toward the back from the GC

The center of gravity for the Inventive Example club head was achieved by the configuration and dimensions of the club head in additional to adding a weight of 31.5 grams to the sole plate. Other known methods of weight manipulation can be used to achieve the inventive center of gravity location as set forth above.

Thus, referring to FIG. **1**, in the club head example of the present invention the center of gravity is preferably located along the Z-axis at least 0.10 inches below the geometric face center GC, along the X-axis within 0.01 inches from the geometric face center GC, and along the y-axis within 1.25 inches from the geometric face center GC. The Parameter column of Table 2 describes for each center of gravity location or coordinate the distance that the center of gravity is spaced from the face geometric center GC with respect to a Cartesian Coordinate System along particular axes. The centers of gravity for Comparative Examples 1–3 are not located properly with respect to the inventive requirements along the Z- and X-axes. The center of gravity for the Inventive Example is located properly with respect to the inventive requirements in the Z, X, and Y axes.

TABLE 3

TEST RESULTS

Parameter	Comparative Example 1	Comparative Example 2	Comparative Example 3	Inventive Example
Maximum COR	0.807	0.808	0.829	0.830
Average COR	0.765	0.766	0.783	0.789
Maximum Total Distance (yards)	290	286	291	298
Landing Area (yards^2)	950	255	1000	341

The test results enumerated in Table 3 were generated using computational techniques, which included finite element analysis models. When computer modeling the exemplary club heads, the following assumptions were made: club head loft of 8.5; club head mass of 201 grams; and club head material is 6AL-4V titanium alloy. The golf ball used was a two-piece solid ball. Finite element models were used to predict ball launch conditions and a trajectory model was used to predict distance and landing area. The impact condition for the swing used in the total distance and landing area predictions or tests had a club head velocity of 109.1 mph and an attack angle of +2 degrees, the club was oriented such that the vertical plane of the face was at an angle of 8.5 degrees relative to the velocity vector. The impact condition used for club coefficient of restitution (COR) tests was consistent with the USGA Rules for Golf, specifically, Rule 4-1e Appendix II Revision 2 dated Feb. 8, 1999. The impact conditions prescribed by Rule 4-1e include firing a ball at a stationary club head with a ball velocity of 160 feet per second. Rule 4-1e also prescribes that the velocity vector of the ball is nearly perpendicular to the plane of the club face.

COR or coefficient of restitution is one way of measuring ball resiliency. The coefficient of restitution (COR) is the ratio of the velocity of separation to the velocity of approach. In this model, therefore, COR was determined using the following formula:

$$(v_{club\text{-}post}-v_{ball\text{-}post})/(v_{ball\text{-}pre}-v_{club\text{-}pre});$$

where,

$v_{club\text{-}post}$ represents the velocity of the club after impact;

$v_{ball\text{-}post}$ represents the velocity of the ball after impact;

$v_{club\text{-}pre}$ represents the velocity of the club before impact (a value of zero for USGA COR conditions); and

$v_{ball\text{-}post}$ represents the velocity of the ball before impact.

The COR, in general, depends on the shape and material properties of the colliding bodies. A perfectly elastic impact has a COR of one (1), indicating that no energy is lost, while a perfectly inelastic or plastic impact has a COR of zero, indicating that the colliding bodies did not separate after impact resulting in a maximum loss of energy. Consequently, high COR values are indicative of greater ball velocity and travel and total distance. Club heads with thinner faces also have higher COR values, as exhibited by Comparative Example 3 as compared to the Comparative Club 1. However, unexpectedly the Inventive Example has the highest COR. For the inventive club head, preferably the COR is greater than about 0.81, and more preferably greater than about 0.83.

It is expected that as the COR increases the ball flight distance will increase and the maximum total distance will increase. The Inventive Example with the highest COR also has the highest maximum total distance.

It as also expected that as the COR increases the shot accuracy will decrease. However, the Inventive Example with the highest COR has the greatest accuracy as illustrated by the data for Landing Area. The Landing Area is an area encompassing the position of nine balls, which impact the club face at various locations. The nine impact locations were equally spaced within a rectangular region 1 inch wide and 0.5 inches high, centered on the club face. The club head of the Inventive Example has a very small Landing Area of 341 square yards. The Comparative Example 3, which is the only Comparative Example with a sufficient COR of at least 0.81, has a Landing Area of 1000 square yards which is significantly greater than the Landing Area for the Inventive Club. The smaller the landing area, the greater the accuracy of the club.

Several alternative embodiments of the invention are possible. The features of the invention include flexural stiffness for distinct zones or portions of the club face as well as the ratio of flexural stiffness between portions. A wide variety of rib configurations and material alternatives may be used to attain the requisite flexural stiffness and flexural stiffness ratio of the face portions.

In FIGS. **3**–**3**B, a preferred embodiment of the club **10** is shown. The club **10** has a face **16** with the following construction. The central zone **36** has a thickness, t_1, of about 0.150 inches, the intermediate zone **38** has thickness, t_2, of about 0.075 inches, and the perimeter zone **40** has thickness, t_3, of about 0.120 inches. Furthermore, the central zone **36** comprises about 20% of the total face surface area and the perimeter zone **40** is less than about 20% of the total face surface area. Each of the three zones **36**, **38**, and **40** have uniform thickness and are constructed from a single homogeneous material, preferably a titanium alloy, with a Young's Modulus (Et) of approximately 16.5×10^6 lbs/in^2.

Referring to FIGS. **3**–**3**B, the flexural stiffness, FSz, can also be defined by the following relationship:

$$FS_Z = \sum_{i=1}^{n} \frac{A_i}{\sum_{j=1}^{n} A_j} E_i t_i^3$$

where;

A_i is defined as the area of a constituent within a zone.

E_i is the Young's Modulus in pounds per square inch of a constituent within a zone

t_i is the thickness or average thickness in inches of a constituent within a zone

n is the number of constituents within a zone.

Using this expression, the flexural stiffness can be calculated for the central and abutting zones and a ratio, defined as the flexural stiffness ratio, can be computed. The flexural stiffness ratio for the preferred embodiment golf club head **10** is calculated as,

$$FS_C = E_C t_C^3 = (16.5\times10^6 16/\text{in}^2)(0.15\text{ in})^3 = 55{,}688\text{ in}\cdot\text{lb}$$

$$FS_I = E_I t_I^3 = (16.5\times10^6 16/\text{in}^2)(0.075\text{ in})^3 = 6981\text{ in}\cdot\text{lb}$$

$$\frac{FS_C}{FS_I} = 8$$

In FIG. 6, an alternate embodiment of the club head **110** is shown to illustrate an alternate construction of face **116** that results in a similar flexural stiffness ratio of the central to the abutting intermediate zone as the embodiment of FIG. **3**. In the club head **110**, the face **116** has an elliptically shaped central zone **136** there about and adjacent thereto is an intermediate zone **138**. The central zone **136** is about 30 percent of the total face surface area.

Referring to FIGS. 7–7B, the central zone **136** includes a ribbed support structure **137***a* (shown in phantom) that extends from the interior surface of the face. The ribbed structure asterisk-shaped, which is formed of a plurality of ribs or legs stiffens the central zone. The thickness of the ribbed portion **137***a* of the central zone t_{1A} is about 0.225 inches. The width of the rib, w, is about 0.085 inches. The thickness of the remaining portion **137***b* between the ribs of the central zone t_{1B} is about 0.09 inches. The ribbed structure **137***a* is defined such that it comprises about 25 percent of the surface area of the central zone. The intermediate zone **138** has a uniform thickness, t_2, of about 0.075 inches and extends to the boundary of the face **116** with no defined perimeter zone. The face **116** is preferably made of a homogeneous titanium alloy with a Young's Modulus (Et) of 16.5×10^6 lbs/in^2.

Referring to FIGS. 6–7B, the flexural stiffness ratio between the central and the abutting intermediate zone is computed.

Ellipse

Major axis $2b$=2"

Minor axis $2a$=1"

Ellipse Area A_C=πb a

=π(1)(0.5)=1.57 in^2

Rib Area WI=0.085 in

LI=4.60 in

A_r=WI LI=0.39 in^2

Non Rib Area A_{TVR}=A_z–A_r=(1.57–0.39)=1.18 in^2

$$FS_C = \frac{A_r}{A_C}E_A(t_{1A})^3 + \frac{A_{NR}}{A_C}E_{NR}(t_{1B})^3$$

$$= (.25)\left(16.5\times10^6\frac{16}{\text{in}^2}\right)(.225)^3 + (0.75)\left(16.5\times10^6\frac{16}{\text{in}^2}\right)(.090)$$

$$= 56008\text{ in}\cdot\text{lb}$$

$$FS_I = E_I t_2^3 = \left(16.5\times10^6\frac{16}{\text{in}^2}\right)(0.075\text{ in})^3$$

$$= 6961\text{ in}\cdot\text{lb}$$

$$\frac{FS_C}{FS_I} = 8.05$$

It should be noted that ribs, welts, pimples, or other discrete thickness variations within a zone are handled as discrete elements within a particular zone and are computed in accordance with the governing definition for flexural stiffness previously detailed.

In FIG. **8**, an alternate embodiment of the club head **210** is shown to illustrate an alternate construction of face **216** that results in a similar flexural stiffness ratio of the central to the abutting intermediate zone as the embodiment of FIG. **3**. In the club head **210**, the face **216** has a central zone **236** and there about and adjacent thereto is an intermediate zone **238**. The central zone **236** is about 30 percent of the total face surface area. The club head **210** does not have a defined perimeter zone.

Referring to FIGS. 9–9A, the central zone **236** has a uniform thickness of t_1 of about 0.140 inches. The intermediate zone **238** has a continuously tapering thickness from the face perimeter inward to the central zone **236**. The thickness of the intermediate zone **238** is defined to change linearly.

The intermediate zone **238** has an inner thickness, t_{2A}, of about 0.07 inches at the boundary of the central zone **236** and the intermediate zone **238**. The intermediate zone **238** has an outer thickness, t_{2B}, of about 0.10 inches. The outer thickness is at the face perimeter. In instances of nonuniform thickness, within the zone, and primarily in relation to a continuous taper, an average thickness may be used to compute the flexural stiffness for the zone. This approximation simplifies the calculation and is physically based on elastic shell theory.

In this embodiment, two different homogenous materials are used. The central zone **236** is preferably made from a stainless steel having a Young's Modulus (Es) of 30.0×10^6 lbs/in^2 and the adjacent intermediate zone **238** is made from a titanium alloy with a Young's Modulus (Et) of 16.5×10^6 lbs/in^2.

Referring to FIGS. 8–9A, the flexural stiffness ratio between the central and adjacent zone is computed.

$$FS_C = E_C t_1^3 = \left(30\times10^6\frac{16}{\text{in}^2}\right)(0.140\text{ in})^3$$

$$= 82320\text{ in}\cdot\text{lb}$$

$$FS_I = E_I((t_{2A} + t_{2B})/2)^3$$

$$= 16.5\times10^6\frac{16}{\text{in}^2}([0.1 + 00.7]/2)^3$$

-continued

$$= 10133 \text{ in} \cdot \text{lb}$$

$$\frac{FS_C}{FS_I} = 8.12$$

In FIG. **10**, an alternate embodiment of the club head **310** is shown to illustrate an alternate construction of face **316** that results in a similar flexural stiffness ratio of the central to the abutting intermediate zone as the embodiment of FIG. **3**. In the club head **310**, the face **316** has an elliptically shaped central zone **336** there about and adjacent thereto is an intermediate zone **338**. The central zone **336** is formed using two materials **337***a* (shown in phantom) and **337***b* (shown in phantom).

The central zone **336** has a uniform thickness, t_1, of about 0.140 inches. The first material **337***a* is a titanium alloy with a Young's Moduli, Et, of 16.5×10^6 lbs/in^2. The second material **337***b* is stainless steel and has a Young's Moduli, Es, of 30×10^6 lbs/in^2. The central zone **336** is comprised of about 60 percent stainless steel,**337***b*.

Furthermore, the central zone **338** is elliptically shaped and comprises about 25 percent of the total face surface area. The intermediate zone **338** with the perimeter zone **340** comprises of no more than 20 percent of the total face surface area. The intermediate zone has a uniform thickness, t_2, of about 0.08 inches and is constructed from the same titanium alloy as the central zone **336**.

Referring to FIGS. **10**–**11**A, the flexural stiffness ratio between the central and intermediate zone **336** and **338** is computed.

Ellipse Area, A_C 2b=1.8"

2*a*=0.9"

Ac 32 πb a

A_C=1.272 in^2

Area Steel, A_S=0.763 in^2

Area Non Steel, $A_{NS}=A_C-A_S$

$$FS_C = \frac{A_S}{A_C}E_S t_1^3 + \frac{A_{NS}}{A_C}E_T t_1^3$$

$$= (.6)\left(30\times10^6\frac{16}{\text{in}^2}\right)(.14)^3 + (0.4)\left(16.5\times10^6\frac{16}{\text{in}^2}\right)(.14)^3$$

$$= 67502 \text{ in} \cdot \text{lb}$$

$$FS_I = E_T t_2^3 = \left(16.5\times10^6\frac{16}{\text{in}^2}\right)(0.08 \text{ in})^3$$

$$= 8448 \text{ in} \cdot \text{lb}$$

$$\frac{FS_C}{FS_I} = 8.0$$

The golf club head embodiments **10**, **110**, **210**, and **310** discussed in FIGS. **1**–**11**A demonstrate four unique face constructions which result in a similar flexural stiffness ratio, where the central zone to the adjacent zone ratio is greater than or equal to three and, more particularly, about eight. In cases where the face construction is uncertain due to manufacturing tolerances or methods or for other possible reasons, a nondestructive test method of determining the flexural stiffness ratio for a given face construction may be used.

Referring to FIG. **12**, a typical club **410** is shown with an unknown face thickness profile. Preferably, something is known regarding the construction materials of the face or has been determined experimentally through test methods known to those of ordinary skill in the art. In FIG. **7**, a random distribution of points is shown on face **416**. This distribution is referred to herein as a "point cloud" or predetermined point distribution. Points labeled C indicate a position in the central zone **436**. Points labeled I indicate a position in the intermediate zone **438**. Points labeled P indicate a position in the perimeter zone **440**. The numbers following the position letters "C", "I" or "P" indicate relative face position.

Using the defined point cloud, an ultrasonic measurement device **450** (as shown in FIG. **13**) can be used to map the face **416** thickness profile. The point cloud technique has the advantage of capturing discrete variations in face thickness such as the presence of ribs or abrupt thickness changes. One recommended ultrasonic measurement device includes a Panametrics Model 25DL ultrasonic thickness device **455** and a Panametrics model M208 probe **460**. The sensor or device **455** and the probe or transducer **460** are commercially available from Panametrics, Inc. of Waltham, Mass.

Referring to FIG. **12**, the face thickness data obtained from the ultrasonic measurement, along with material modulus information, is then used to define the central, intermediate and possibly perimeter zones. The central zone **436** is defined by constructing an area comprising of a specific percentage of the total face surface area and including the geometric center GC. The point cloud thickness data within the defined zone is then averaged or broken into distinct elements within the zone. If the latter is required, the area percentages for the elements within the zone are calculated. The calculation for FSz previously outlined is then carried out to determine the flexural stiffness ratio between the central and adjacent zone **436** and **438**, respectively.

The following example illustrates the technique. In Table 4, random face thickness measurements are shown for titanium alloy club **410** (as shown in FIG. **12**) with an unknown face thickness profile. The technique described above is used.

TABLE 4

ULTRASONIC FACE THICKNESS DATA

Position	Thickness	Position	Thickness	Position	Thickness
C1	0.132	I1	0.102	P1	0.110
C2	0.127	I2	0.103	P2	0.115
C3	0.131	I3	0.098	P3	0.117
C4	0.125	I4	0.096	P4	0.119
C5	0.136	I5	0.088	P5	0.120
C6	0.130	I6	0.089	P6	0.114
C7	0.127	I7	0.089	P7	0.117
C8	0.129	I8	0.094	P8	0.109
C9	0.133	I9	0.097	P9	0.108
C10	0.138	I10	0.099	P10	0.111
C11	0.134	I11	0.100	P11	0.115
C12	0.131	I12	0.103	P12	0.118
		I13	0.106	P13	0.109
		I14	0.102	P14	0.108
		I15	0.105	P15	0.112
		I16	0.101	P16	0.112
		I17	0.100	P17	0.115
		I18	0.103	P18	0.109
		I19	0.107	P19	0.117
		I20	0.106	P20	0.120

FIG. **12** shows the measured data points and the projected central, intermediate and perimeter zones **436**, **438** and **440**. Based on these projected areas, the percentage of each zone can be estimated or computed more accurately by other techniques, such as face scanning. The data defines three zones, the actual central zone with an average thickness of 0.131 inches; the actual intermediate zone with an average thickness of 0.099 inches, and the perimeter zone with an average thickness of 0.114 inches. Furthermore, the area of

the central zone has been estimated to be about 23 percent of the total face surface area, and the perimeter zone is estimated to comprise of about 35 percent of the total face area. Based on this information a flexural stiffness ratio can be computed as set forth below.

With regard to the calculation of face flexural stiffness and the flexural stiffness ratio. The aforementioned embodiments and point cloud example all consider faces, which possess the property of material isotropy and symmetry with regard to a mid-surface of the face structure. Material isotropy is not a necessary condition of the invention. And the invention can include club heads with anisiotropic constructions. The flexural stiffness or the flexural stiffness ratio can be used with ansiotropic constructions. These calculations would still be applicable but of a more general form, as discussed below.

The notion of symmetry with regard to a mid-surface of the face simplifies the calculations of flexural stiffness. The calculation of flexural stiffness for asymmetric shell structures with respect to the mid-surface are common in composite structures where laminate shell theory is applicable. Here the Kirkhoff shell assumptions are applicable. Referring to FIG. **14**, an unsymmetric isotropic laminate **500** is shown with N lamina or layers **502**. Furthermore, the laminate is described to be of thickness, t, with x_i being directed distances or coordinates in accordance with FIG. **14**. The positive direction is defined to be downward and the laminate points x_i defining the directed distance to the bottom of the K_{th} laminate layer. For example, $x_0=-t/2$ and $x_N=+t/2$ for a laminate of thickness t made comprised of N layers.

Further complexity is added if the lamina can be constructed of multiple materials, M. In this case, the area percentage, Ai is included in the flexural stiffness calculation, as before in a separate summation over the lamina. The most general form of computing the flexural stiffness is:

$$FSz = \frac{1}{3}\sum_{j=1}^{N} Ar_j \sum_{i=1}^{M} [E(x_i^3 - x_{i-1}^3)]_i$$

Due to the geometric construction of the lamina about the mid-surface, asymmetry results, i.e., the laminate lacks material symmetry about the mid-surface of the laminate. However, this asymmetry does not change the calculated values for the flexural stiffness only the resulting forces and moments in the laminate structure under applied loads.

A conceivable example of this type of construction would be a titanium alloy face of uniform thickness and modulus E_t, where the central zone is backed by a steel member of with half the thickness of the titanium portion, and having modulus E_s. In this case, the flexural stiffness would be approximated in the following manner:

$$FSz = \frac{1}{3}\sum_{i=1} [E(x_i^3 - x_{i-1}^3)]_i$$

$$= \frac{1}{3}\{[E_s(x_0^3 - x_1^3)] + [E_t(x_1^3 - x_2^3)]\} \text{ here,}$$

$$x_0 = \frac{-t}{2}, x_1 = \frac{t}{2} - Wl, x_2$$

$$x_2 = \frac{t}{2}, \text{ substitution yielding}$$

-continued

$$= \frac{1}{3}\left\{\left[E_s\left(\left(\frac{-t}{2}\right)^3 - \left(\frac{t}{2} - Wl\right)^3\right)\right] + \left[E_t\left(\left(\frac{t}{2} - Wl\right)^3 - \left(\frac{t}{2}\right)^3\right)\right]\right\}$$

Referring to FIG. **15**, a testing apparatus **650** for measuring inertance is schematically illustrated. Generally, inertance is a frequency response. More specifically, inertance is a measure of the stiffness of a structure, in this instance the club face, at various frequencies of vibration. The units of inertance are acceleration units over force units. A preferred first resonant frequency for the inventive face is located where the inertance is maximized.

The test apparatus **650** includes club head **652**, a rigid mass **654**, an accelerometer **656**, and an impact hammer **658**. The mass **654** is preferably a cylindrical steel rod with a diameter of 1 inch. Referring to FIGS. **15** and **15A**, the mass **654** preferably has a cylindrical cavity **659** at one end for receiving the accelerometer **656** and a slot **660** to accommodate the cable **662**. The accelerometer **656** is connected to the geometric center of the face of the club head **652** with a high modulus adhesive **657**, such as a cyanoacrylate based adhesive, Loctite 409, available from Loctite Corp., Newington, Conn. The mass **654** is then placed over the accelerometer **656** and also secured to the club face with cyanoacrylate adhesive. The combined mass of the mass **654** and the accelerometer **656** should equal the mass of a golf ball or 1.62 oz. The impact hammer **658** has an integral force transducer **658***a* and is movable toward and away from the free end **654***a* of the rigid mass, as indicated by the arrow I, to impact the mass **654**, which is attached to the club head face at the geometric center. The impact force or excitation force is normal to the club face, and upon impact is transmitted to the face through the mass **654**.

The testing apparatus **650** further includes a junction box and ICP power supply **660** and cables **662** electrically connected to the accelerometer **656** and the impact hammer transducer **658***a*. The junction box and ICP power supply **660** is in turn connected to a digital signal processing board **664**, located within a computer **665** with signal processing software **667**. The digital signal processing board **664**, computer **665** and software **667** are used to condition frequency signals and calculate the frequency response functions. The accelerometer **656**, transducer **658***a*, junction box and ICP power supply **660**, cables **662**, digital signal processing board **664**, computer **665**, and software **667** are commercially available and one of ordinary skill in the art can readily identify and obtain inertance values for golf clubs using these components. Typically, the data from 20 impacts are averaged to reduce noise and improve measurement accuracy. The following TABLE 5 lists specific model numbers for the vibration equipment shown in FIG. **13**.

TABLE 5

VIBRATION EQUIPMENT

Reference Number	Part	Model #	Supplier
656	Accelerometer	352A10	Modal Shop of Cincinnati, OH
658	Impact Hammer	086C01	Modal Shop
662	Cables	002T01	Modal Shop
660	Junction Box & ICP power	BNC 2140	National Instruments of Dallas, TX
664	DSP Board	NI 4551	National Instruments

TABLE 5-continued

VIBRATION EQUIPMENT

Reference Number	Part	Model #	Supplier
665	Computer	Dell Optiplex Gxi	Dell Computers of Round Rock, TX
667	Software	Virtual Bench DSA 2.5.1	National Instruments

Referring to FIG. 16, a graph of inertance versus frequency for a conventional club head is shown. The conventional club head is a Callaway Great Big Bertha War Bird with an eight degree loft. The inertance I shown is the result of testing using apparatus 650 of FIG. 15. The point I1 at a frequency of 3330 Hertz represents the first primary resonant frequency which occurs at the first primary maxima inertance for the inertance function I. A maxima which does not represent a primary resonant natural frequency of the face is also present in FIG. 16 at a frequency of 2572 Hertz, which is the point I2. These secondary maxima I2 are characterized by inertance transitions of a magnitude of less than 10 decibels. These secondary maxima may be due to crown, sole or skirt vibrations that are not acting perpendicular to the plane of the club face. Secondary maxima do not correlate with COR and ball velocity, since the vibration response is either small in magnitude or alternately not coincident with ball response. The COR for the conventional club head tested was measured in accordance with USGA, Rule 4-1e Appendix II Revision 2 dated Feb. 8, 1999 and was found to be 0.785. The preferred first primary resonant frequency of vibration is defined by the following relationship:

$$1/(2*\text{contact duration}) < I1 < 3/(2*\text{contact duration})$$

The contact duration is the time interval during which the ball is in contact with the club face. The contact duration for a typical driver impact is about 500 microseconds. Thus, the preferred primary resonant frequency of vibration for the club head is between about 1000 and 3000 Hz. The closer the COR is to the lower limit, the higher the COR and thus the higher the rebound ball velocity. More preferably, the first primary resonant frequency is less than 2900.

FIG. 17 illustrates the inertance function of the invention club head. The first primary resonant frequency is at 2632 Hz, and the COR of this invention club was measured to be 0.824. The COR of the invention club is greater than the conventional club of FIG. 16, and therefore will provide greater ball rebound velocity.

Several example club heads were produced with two commercially available titanium alloys 6AL-4V and SP700. The clubs were produced with a variety of uniform face thickness'. FIG. 18 illustrates that as face thickness is reduced for a given titanium alloy the COR increases in a linear fashion. However, different titanium alloys with slightly different moduli have distinct trend lines and thickness alone is insufficient to predict COR. FIG. 19 illustrates a plot of COR versus first primary resonant frequency for the same set of club heads as those of FIG. 18. FIG. 18 illustrates that first primary resonant frequency is predictive of COR regardless of titanium alloy. The first primary resonant frequency of a club head may be used as a quality control factor to ensure compliance with USGA COR rules.

While various descriptions of the present invention are described above, it should be understood that the various features of each embodiment can be used alone or in any combination thereof. Therefore, this invention is not to be limited to only the specifically preferred embodiments depicted herein. Further, it should be understood that variations and modifications within the spirit and scope of the invention may occur to those skilled in the art to which the invention pertains. For example, the face and/or individual portions can have thickness variations in a step-wise or continuous fashion. Other modifications include a perimeter portion that has a thickness that is greater than or less than the adjacent, intermediate portion. In addition, the shapes of the central, intermediate, and perimeter portions are not limited to those disclosed herein. Accordingly, all expedient modifications readily attainable by one versed in the art from the disclosure set forth herein that are within the scope and spirit of the present invention are to be included as further embodiments of the present invention. The scope of the present invention is accordingly defined as set forth in the appended claims.

What is claimed is:

1. A golf club head adapted for attachment to a shaft comprising:

a face having a total face area and a first primary resonant frequency less than about 2900 Hz, the face comprising:

a central zone having a first perimeter and a first flexural stiffness, wherein the central zone comprises between 15% and 60% of the total face area, and wherein the central zone includes a geometric center of the face;

an intermediate zone surrounding the first perimeter of the central zone, the intermediate zone having a second flexural stiffness, wherein the first flexural stiffness of the central zone is at least 25,000 lb-in and greater than the second flexural stiffness of the intermediate zone; and

a perimeter zone around the intermediate zone, wherein the area of the perimeter zone is up to 30% of the total face area.

wherein the face exhibits a coefficient of restitution greater than or equal to 0.81.

2. The golf club head of claim 1, wherein the first flexural stiffness of the central zone is at least three times greater than the second flexural stiffness of the intermediate zone.

3. The golf club head of claim 2, wherein the first flexural stiffness of the central zone is at least six times greater than the second flexural stiffness of the intermediate zone.

4. The golf club head of claim 3, wherein the first flexural stiffness of the central zone is between six and twelve times greater than the second flexural stiffness of the intermediate zone.

5. The golf club head of claim 1, wherein the perimeter zone has a third flexural stiffness, and wherein the third flexural stiffness is at least two times greater than the second flexural stiffness.

6. The golf club head of claim 1, wherein the intermediate zone has an intermediate zone area being at least about 30% of the total face area.

7. The golf club head of claim 6, wherein the intermediate zone area is from about 30% to about 70% of the total face area.

8. The golf club head of claim 1, further comprising a shell defining an inner cavity with a volume of greater than about 250 cubic centimeters.

9. The golf club head of claim 1, wherein the face has a loft of greater than about 13°.

10. The golf club head of claim 2, wherein the central zone has a first thickness and the intermediate zone has a

second thickness less than the first thickness, and wherein the central zone and the intermediate zone are made of the same material.

11. The golf club head of claim 2, wherein the central zone has a plurality of ribs on an inner surface thereof.

12. The golf club head of claim 1, wherein the club head has a center of gravity and a geometric center, and wherein the center of gravity is within 0.01 inch of the geometric center in a first horizontal direction between a heel and toe of the club head.

13. The golf club head of claim 12, wherein the center of gravity is within about 0.10 inch below the geometric center of the club in a vertical direction.

14. The golf club head of claim 13, wherein the center of gravity is less than about 1.25 inches from the geometric center of the club in a second horizontal direction toward a rear portion of the club head.

15. A golf club head adapted for attachment to a shaft comprising:

a face having a total face area and a first primary resonant frequency less than about 2900 Hz, the face comprising:

a central zone having a first perimeter and a first flexural stiffness, and a central zone area being at least 15% of the total face area, and the central zone including a geometric center of the face; and

an intermediate zone surrounding the first perimeter of the central zone, the intermediate zone having a second flexural stiffness, and the first flexural stiffness is at least 25,000 lb-in and greater than the second flexural stiffness.

16. The golf club head of claim 15, wherein the club head has a center of gravity and a geometric center,

wherein the center of gravity is within 0.01 inch of the geometric center in a first horizontal direction between a heel and toe of the club head,

wherein the center of gravity is within about 0.10 inch below the geometric center of the club in a vertical direction, and

wherein the center of gravity is less than about 1.25 inches from the geometric center of the club in a second horizontal direction toward a rear portion of the club head.

17. The golf club head of claim 15, wherein the second flexural stiffness is less than about 16,000 lb-in.

18. The golf club head of claim 15, wherein the face has a coefficient of restitution of greater than or equal to 0.81.

19. The golf club head of claim 15, wherein the first flexural stiffness is greater than about 55,000 lb-in.

20. The golf club head of claim 15, wherein the central zone has a first average thickness and the intermediate zone has a second average thickness and the first average thickness is greater than 1.5 times the second average thickness.

21. The golf club head of claim 15, further including a shell defining an inner cavity with a volume greater than about 250 cubic centimeters.

22. The golf club head of claim 15, wherein the face has a loft of greater than about 13°.

23. A golf club head adapted for attachment to a shaft comprising:

a face having a total face area, the face comprising:

a central zone having a first perimeter and a first flexural stiffness, wherein the central zone comprises a geometric center of the face, wherein the central zone comprises at least 15% of the total face area, and wherein upon ball impact the central zone exhibits a first deformation amount; and

an intermediate zone surrounding the first perimeter, wherein the intermediate zone has a second perimeter and a second flexural stiffness, wherein a ratio of the first flexural stiffness to the second flexural stiffness is at least 3, and wherein upon ball impact the intermediate zone exhibits a second deformation amount substantially greater than the first deformation amount.

24. The golf club head of claim 23, wherein the first flexural stiffness is at least six to twelve times greater than the second flexural stiffness.

25. The golf club head of claim 24, wherein the first flexural stiffness is about eight times greater than the second flexural stiffness.

26. The golf club head of claim 23, further comprising a perimeter zone surrounding the second perimeter of the intermediate zone, wherein the perimeter zone has a third thickness and a third flexural stiffness.

27. The golf club head of claim 26, wherein the central zone has a first thickness, and wherein the intermediate zone has a second thickness less than the first and third thicknesses.

28. The golf club head of claim 26, wherein the third flexural stiffness is at least two times greater than the second flexural stiffness.

* * * * *

EXHIBIT B

US007041003B2

(12) **United States Patent**
Bissonnette et al.

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(45) **Date of Patent: May 9, 2006**

(54) **GOLF CLUB HEAD WITH VARIABLE FLEXURAL STIFFNESS FOR CONTROLLED BALL FLIGHT AND TRAJECTORY**

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(73) Assignee: **Acushnet Company**, Fairhaven, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/428,051**

(22) Filed: **May 1, 2003**

(65) **Prior Publication Data**

US 2003/0199335 A1 Oct. 23, 2003

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/551,771, filed on Apr. 18, 2000, now Pat. No. 6,605,007.

(51) **Int. Cl.**
A63B 53/04 (2006.01)

(52) **U.S. Cl.** 473/329; 473/345; 473/349

(58) **Field of Classification Search** 473/324–350, 473/290–291

See application file for complete search history.

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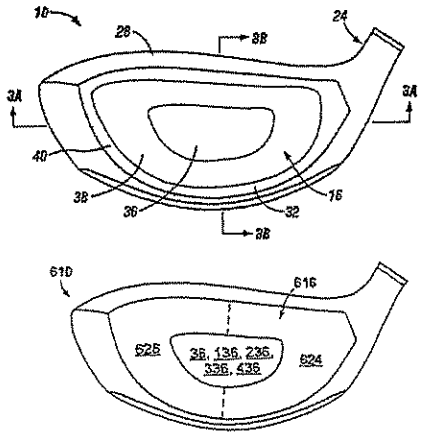
(74) *Attorney, Agent, or Firm*—Kristin D. Wheeler

(57) **ABSTRACT**

The present invention relates to a golf club head with a hitting face. The hitting face comprises a directional control portion, which has at least two zones with different flexural stiffness, such that when the hitting face strikes a golf ball the two zones deform differently to selectively control the direction of the flight of the golf ball. The directional control portion may comprise an upper zone and a lower zone, where the upper zone has a lower flexural stiffness. Alternatively, the lower zone has a lower flexural stiffness. On the other hand, the directional control portion may comprise a left zone and a right zone, and either the left or right zone may have a lower flexural stiffness to selectively control the lateral launch angle either to the left of right. The hitting face may further comprise a central zone disposed within the directional control zone, wherein the central zone has a flexural stiffness of at least about three times greater than the flexural stiffness of the directional control zone.

10 Claims, 13 Drawing Sheets



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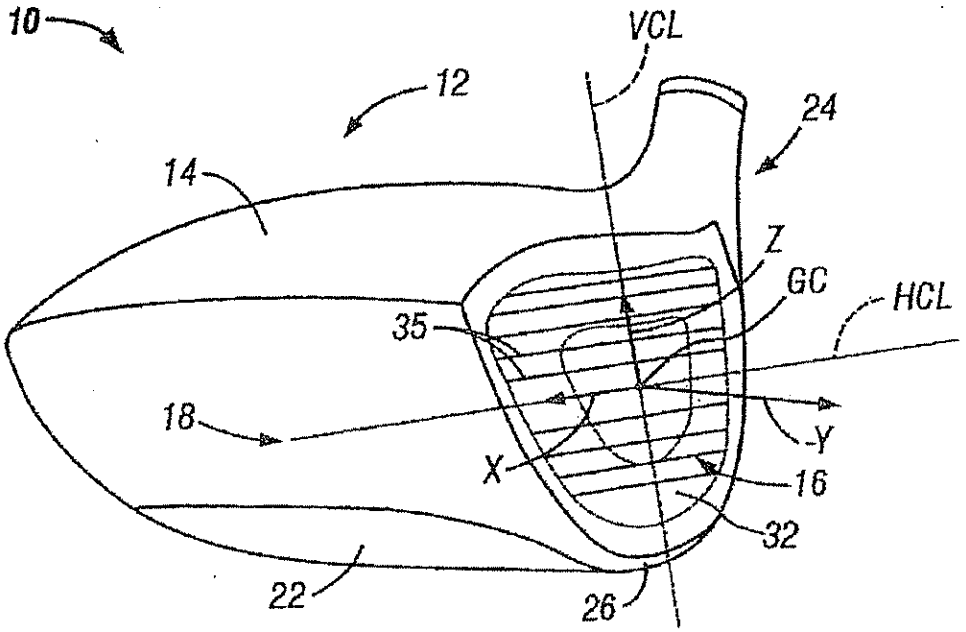

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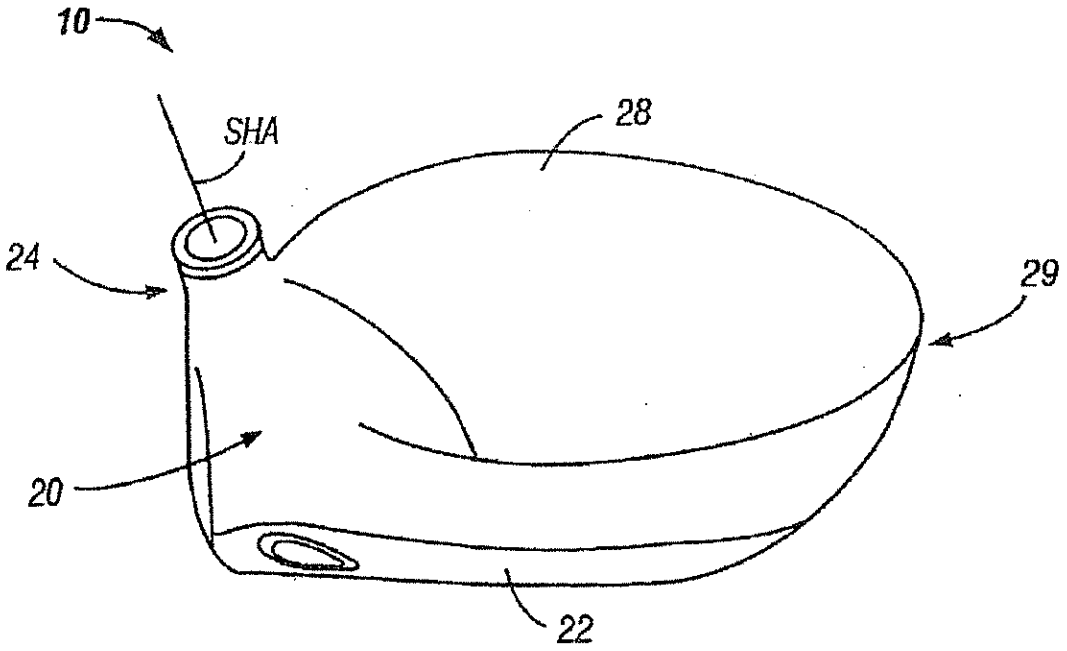
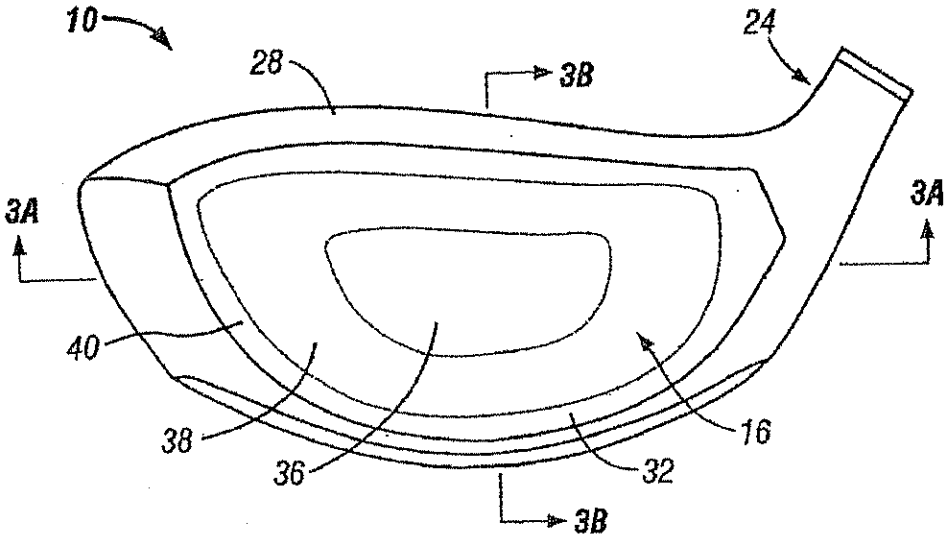


FIG. 2



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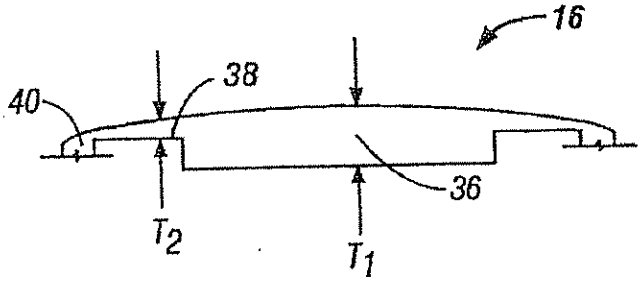

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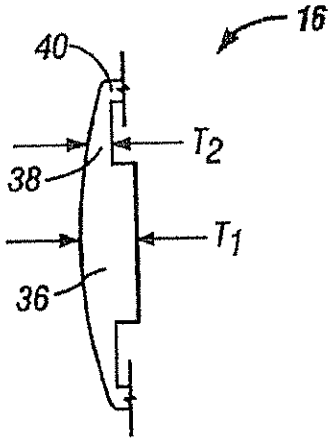

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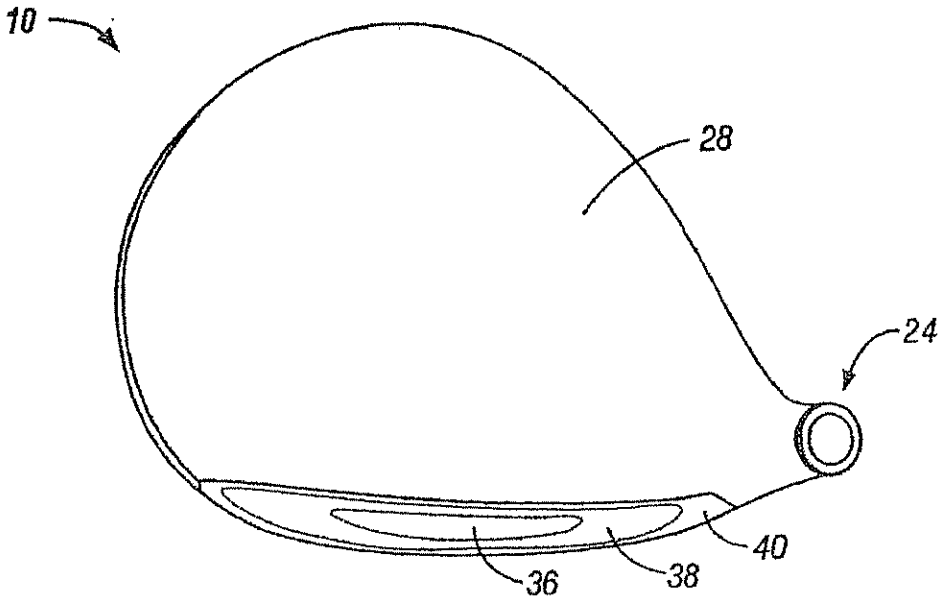

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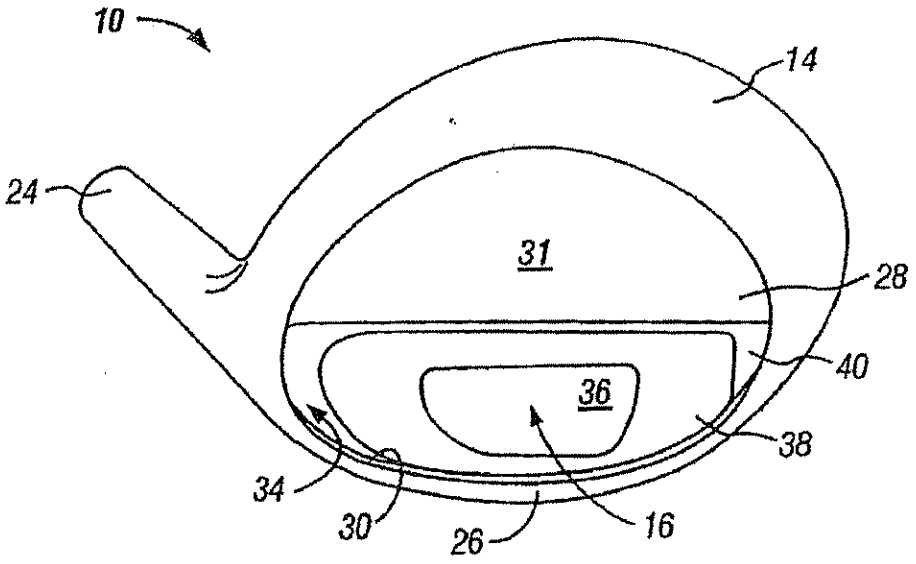

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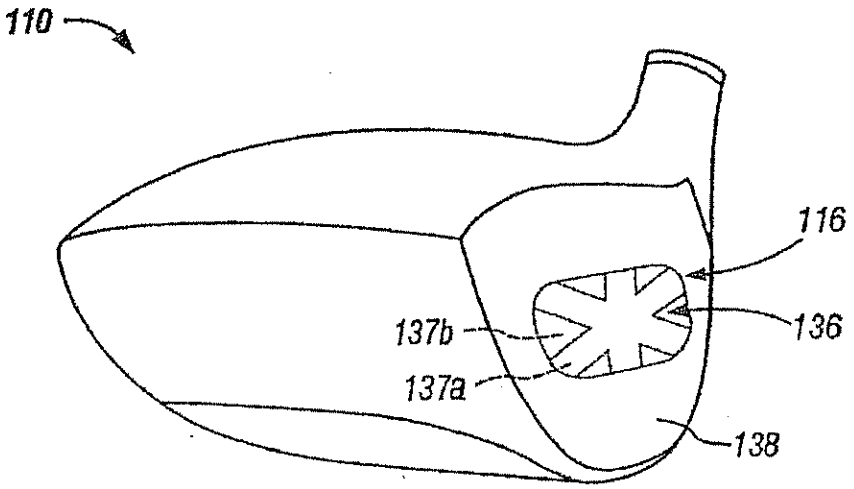

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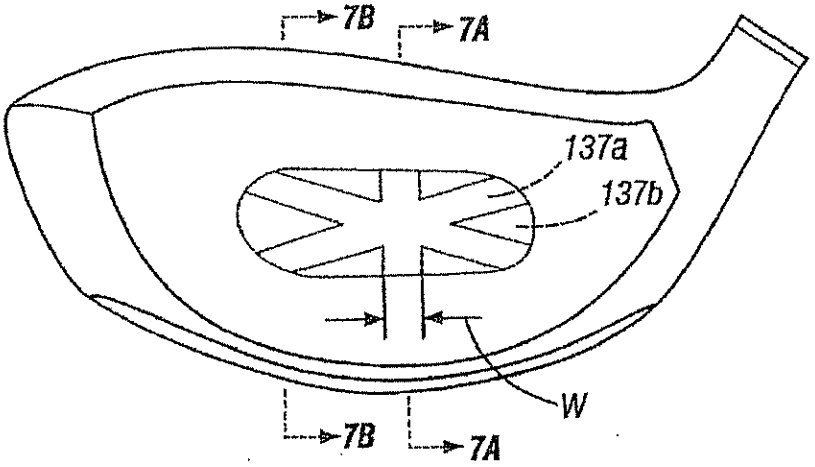

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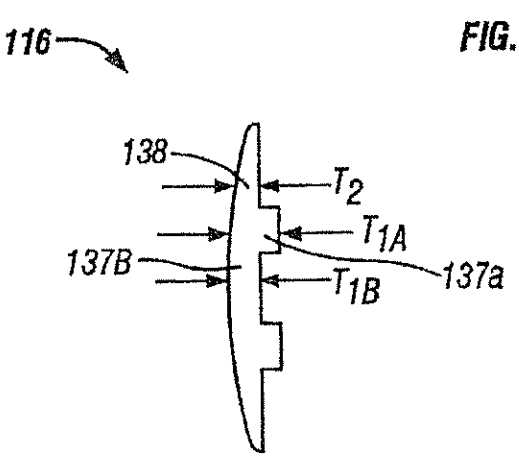
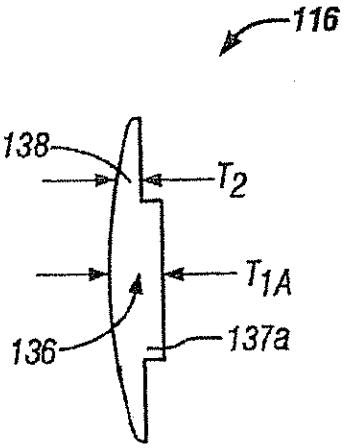


FIG. 7A



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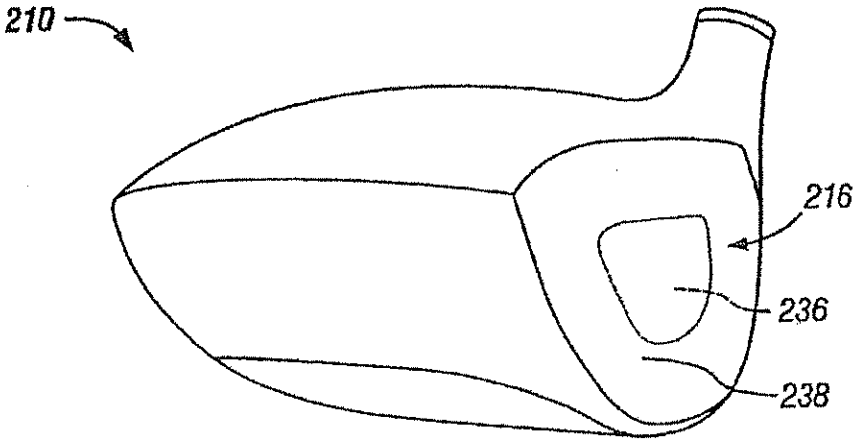

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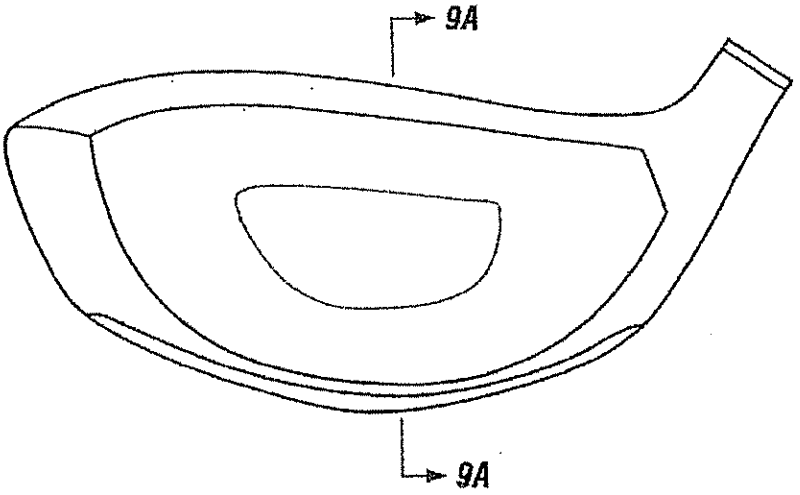

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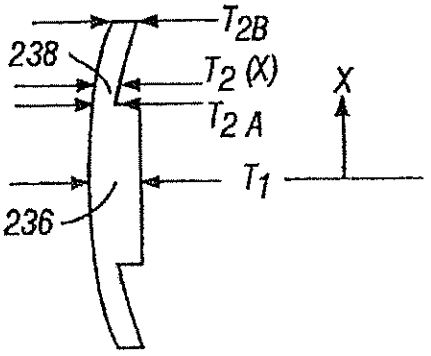
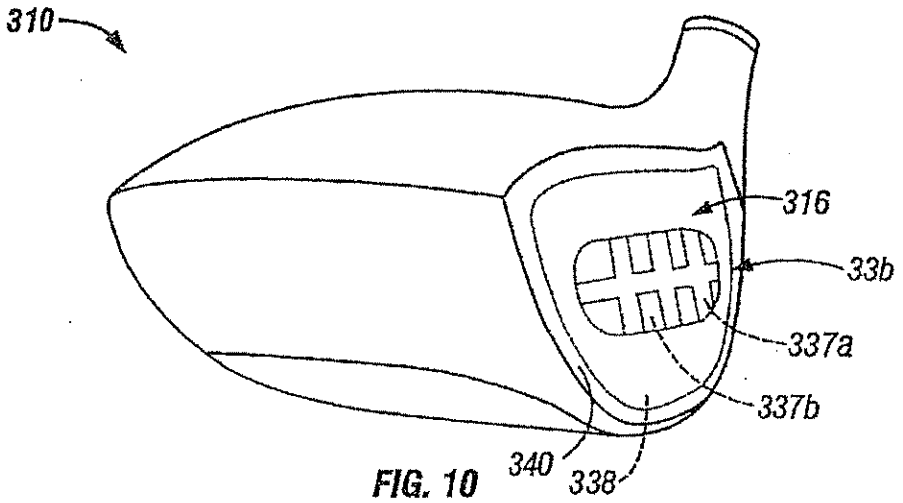


FIG. 9A



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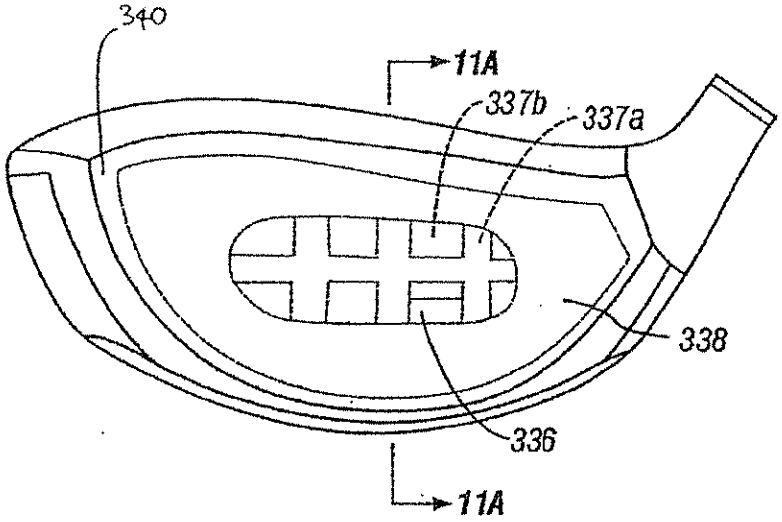

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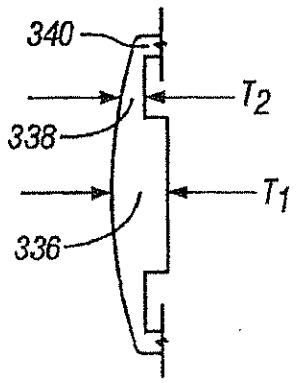

FIG. 11A

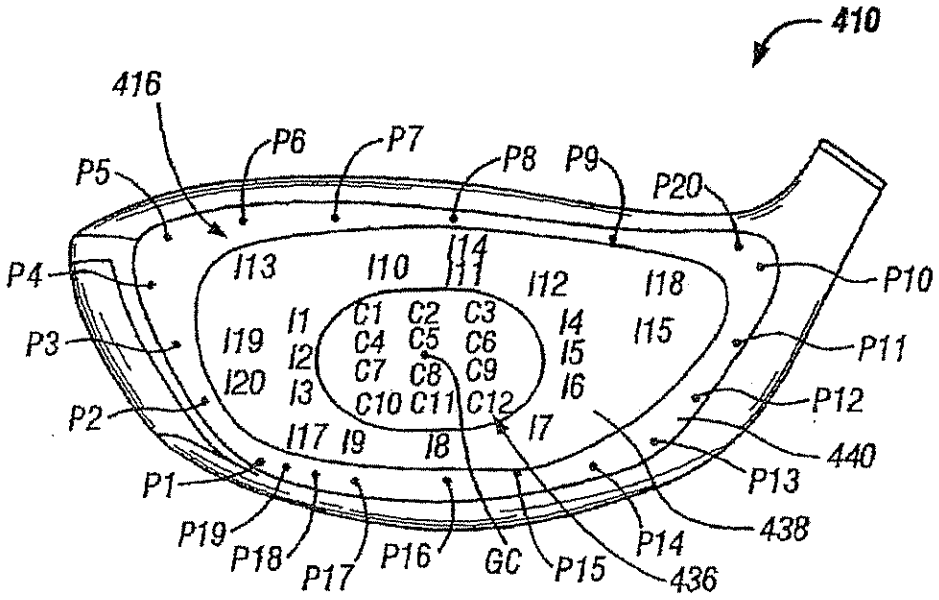
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FIG. 12

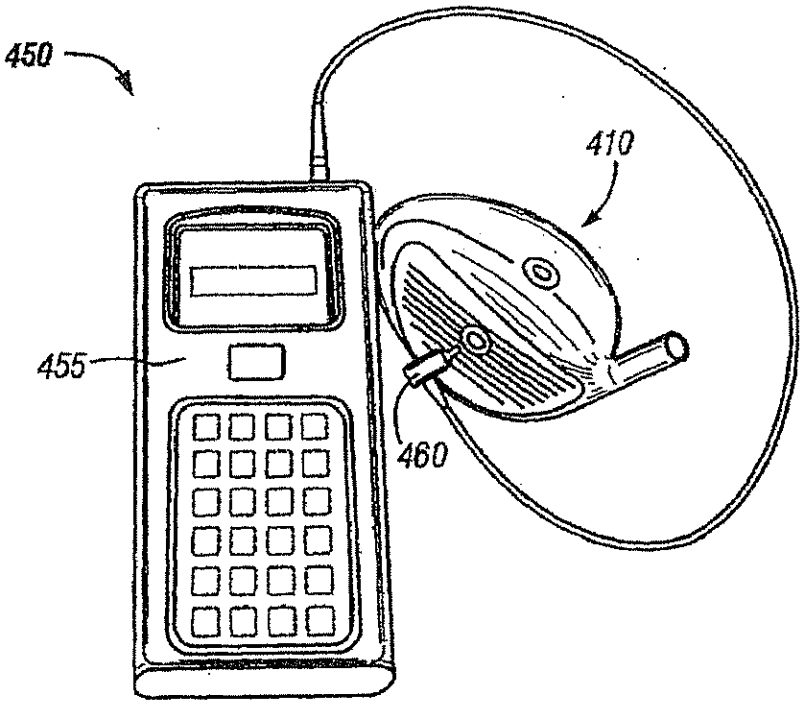
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FIG. 13

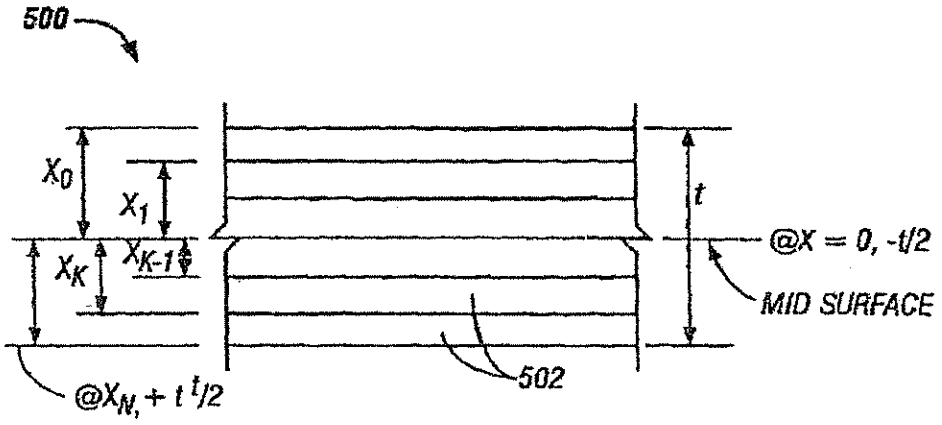

FIG. 14

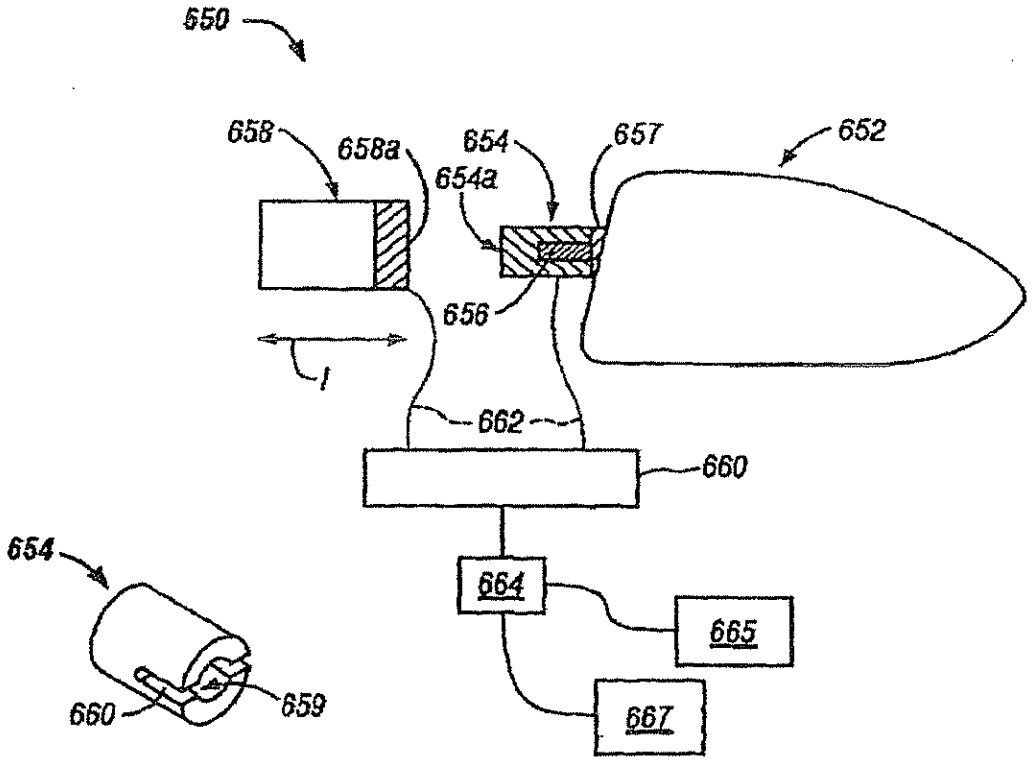

FIG. 15B

FIG. 15A

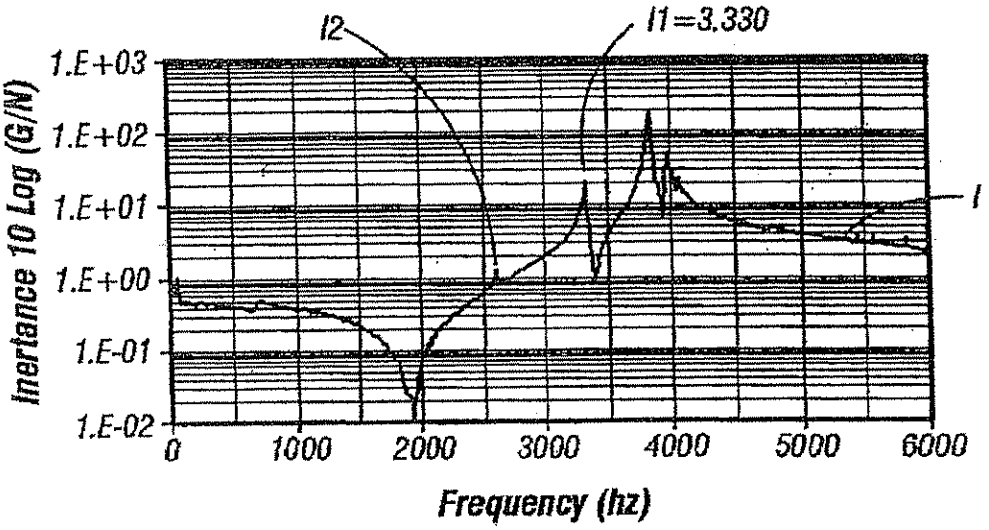
I2
I1=3.330
I
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
Inertance 10 Log (G/N)
0
1000
2000
3000
4000
5000
6000
Frequency (hz)

FIG. 16

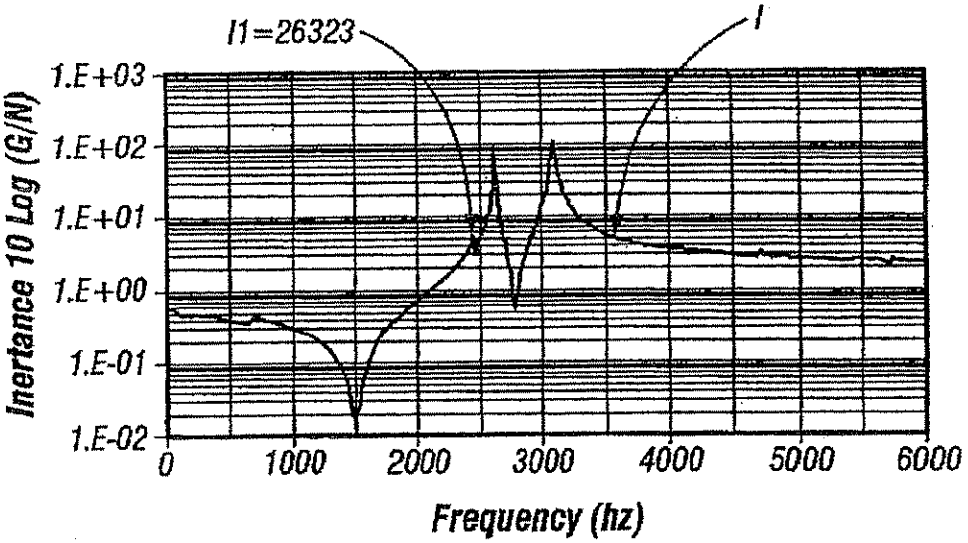
I1=26323
I
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
Inertance 10 Log (G/N)
0
1000
2000
3000
4000
5000
6000
Frequency (hz)

FIG. 17

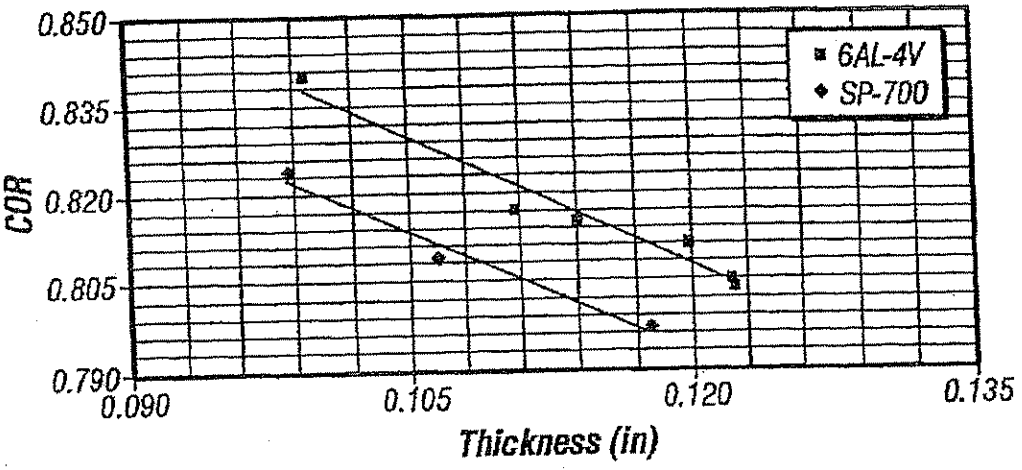
0.850
0.835
0.820
0.805
0.790
COR
0.090
0.105
0.120
0.135
Thickness (in)
6AL-4V
SP-700

FIG. 18

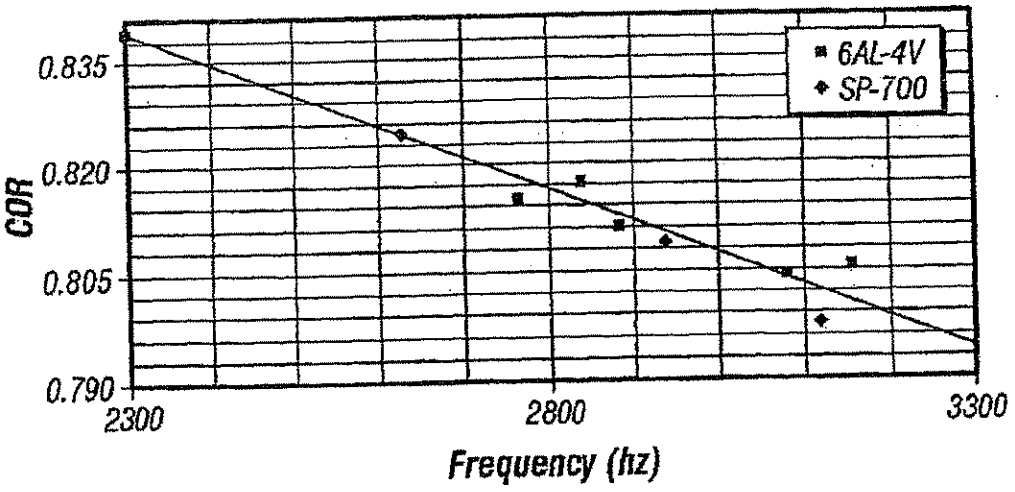
0.835
0.820
0.805
0.790
COR
2300
2800
3300
Frequency (hz)
6AL-4V
SP-700

FIG. 19

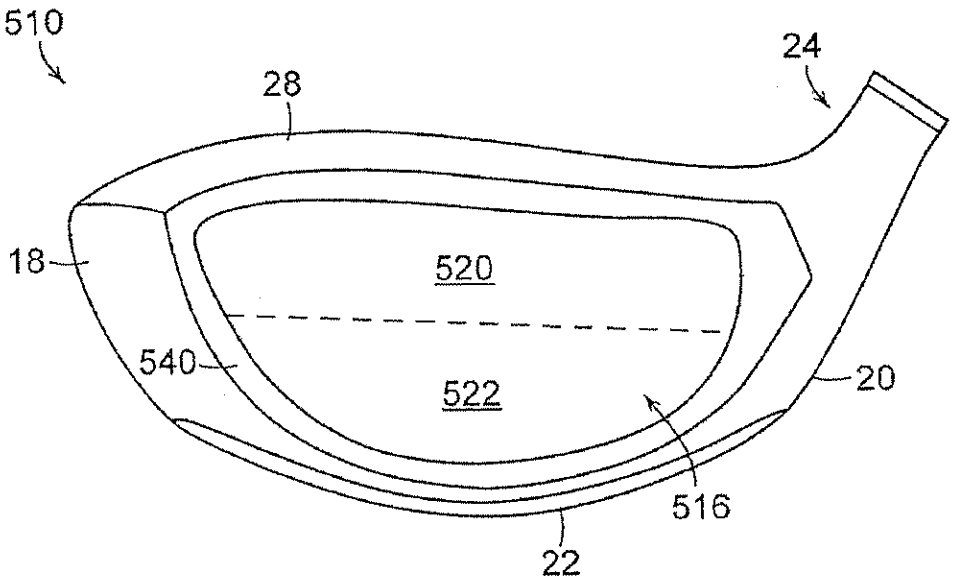
510
28
24
18
520
540
522
20
516
22

FIG. 20

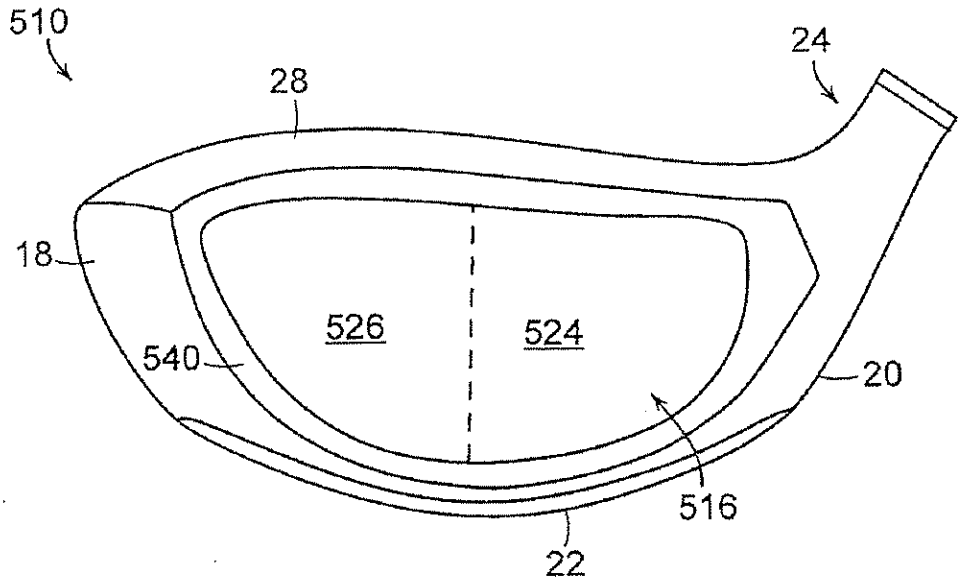
510
28
24
18
526
524
540
20
516
22

FIG. 21

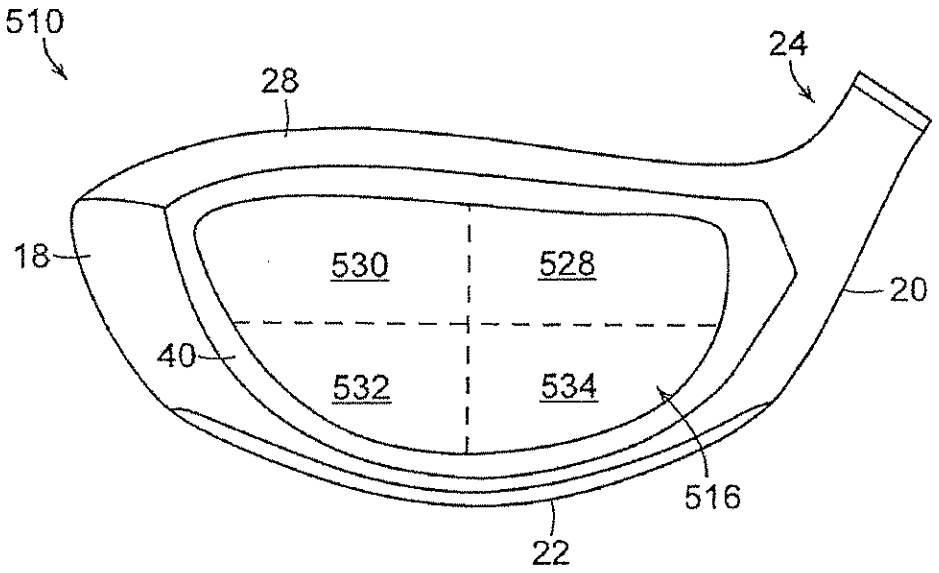

FIG. 22

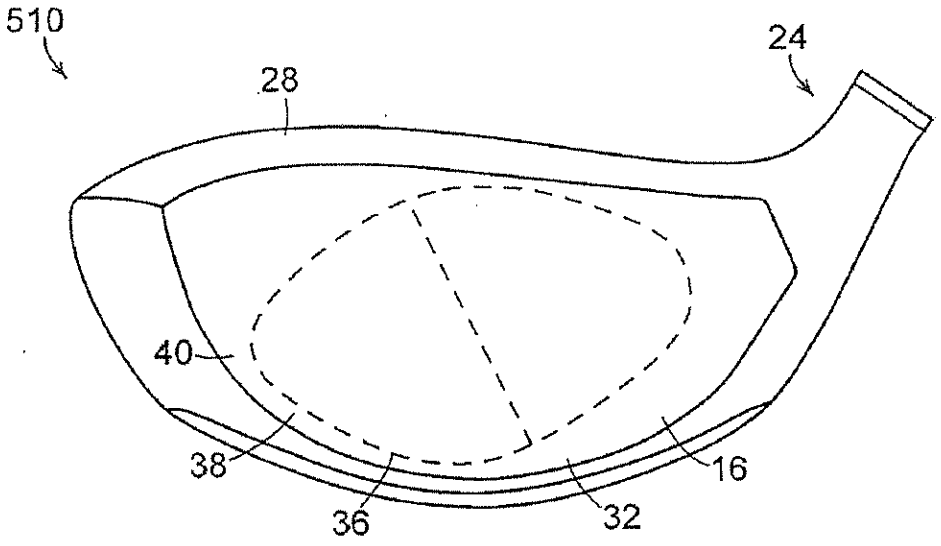

FIG. 23

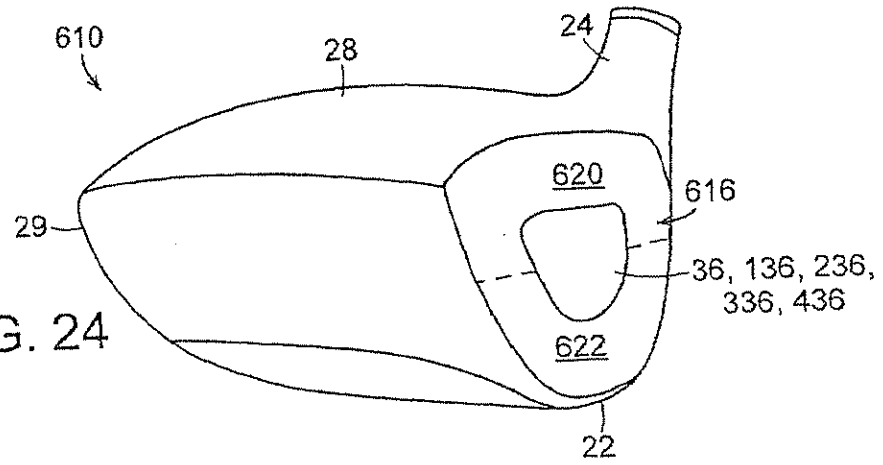

FIG. 24

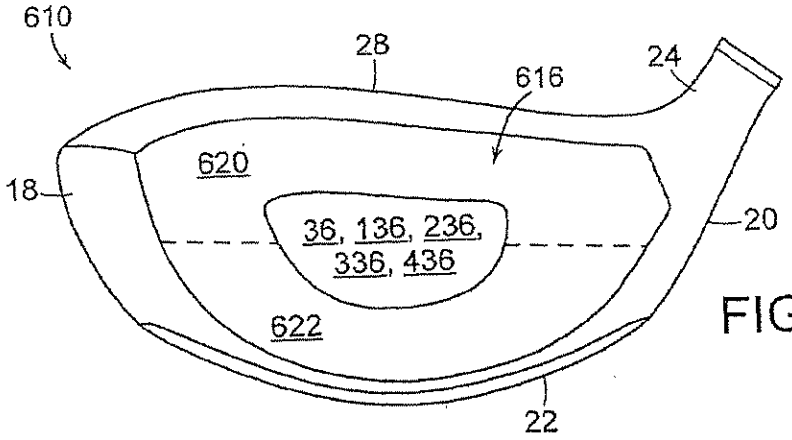

FIG. 25

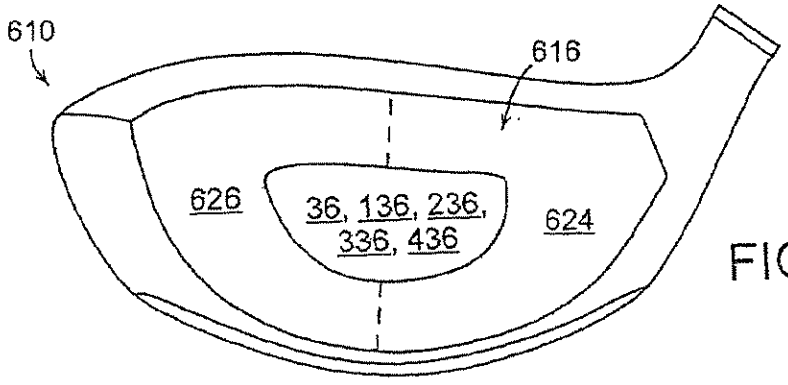

FIG. 26

GOLF CLUB HEAD WITH VARIABLE FLEXURAL STIFFNESS FOR CONTROLLED BALL FLIGHT AND TRAJECTORY

CROSS-REFERENCE TO RELATED APPLICATION

The present application is a continuation-in-part of U.S. patent application Ser. No. 09/551,771 filed on Apr. 18, 2000 now U.S. Pat. No. 6,605,007. The disclosure of the parent patent application is incorporated herein in its entirety

FIELD OF THE INVENTION

The invention is an improved golf club head. More particularly, the invention is a golf club head with an improved striking face having discrete zones with varying flexural stiffness, improved accuracy, and a high coefficient of restitution.

BACKGROUND OF THE INVENTION

The complexities of golf club design are well-known. The specifications for each component of the club (i.e., the club head, shaft, hosel, grip, and subcomponents thereof) directly impact the performance of the club. Thus, by varying the design specifications, a golf club can be tailored to have specific performance characteristics.

The design of club heads has long been studied. Among the more prominent considerations in club head design are loft, lie, face angle, horizontal face bulge, vertical face roll, face progression, face size, sole curvature, center of gravity, material selection, and overall head weight. While this basic set of criteria is generally the focus of golf club engineering, several other design aspects must also be addressed. The interior design of the club head may be tailored to achieve particular characteristics, such as the inclusion of hosel or shaft attachment means, perimeter weights on the face or body of the club head, and fillers within hollow club heads to improve acoustics.

Golf club heads must also be strong to withstand the repeated impacts that occur during collisions between the golf club and the ball. The loading that occurs during this transient event can accelerate the golf ball to about four orders of magnitude greater than gravity. Thus, the club face and body should be designed to resist permanent deformation or catastrophic failure by material yield or fracture. Conventional hollow metal wood drivers made from titanium typically have a uniform face thickness exceeding 0.010 inch to ensure structural integrity of the club head.

Players generally seek a metal wood driver and golf ball combination that delivers maximum distance and landing accuracy. The distance a ball travels after impact is dictated by the magnitude and direction of the ball's translational velocity and the ball's rotational velocity or spin. Environmental conditions, including atmospheric pressure, humidity, temperature, and wind speed further influence the ball's flight. However, these environmental effects are beyond the control of the golf equipment manufacturer. Golf ball landing accuracy is driven by a number of factors as well. Some of these factors are attributed to club head design, such as center of gravity, face curvature and club face flexibility.

The United States Golf Association (USGA), the governing body for the rules of golf in the United States, has specifications for the performance of golf balls. These performance specifications dictate the size and weight of a conforming golf ball. One USGA rule limits the golf ball's initial velocity after a prescribed impact to 250 feet per second ±2% (or 255 feet per second maximum initial velocity). To achieve greater golf ball travel distance, ball velocity after impact must be maximized while remaining within this rule.

Generally, golf ball travel distance is a function of the total kinetic energy imparted to the ball during impact with the club head, along with associated environmental effects. During impact, kinetic energy is transferred from the club and stored as elastic strain energy in the club head and as viscoelastic strain energy in the ball. After impact, the stored energy in the ball and in the club is transformed back into kinetic energy in the form of translational and rotational velocity of the ball as well as the club. Since the collision is not perfectly elastic, a portion of energy is dissipated in club head vibration and in viscoelastic relaxation of the ball. Viscoelastic relaxation is a material property of the polymeric materials used in all manufactured golf balls.

Viscoelastic relaxation of the ball is a parasitic energy source, which is dependent upon the rate of deformation. To minimize this effect, the rate of deformation must be reduced. This may be accomplished by allowing more club face deformation during impact. Since metallic deformation may be purely elastic, the strain energy stored in the club face is returned to the ball after impact thereby increasing the ball's outbound velocity after impact.

A variety of techniques may be utilized to vary the allowable deformation of the club face, including uniform face thinning, thinned faces with ribbed stiffeners and varying thickness, among others. These designs should have sufficient structural integrity to withstand repeated impacts without permanent deformation of the club face. In general, conventional club heads also exhibit wide variations in the coefficient of restitution (COR) depending on the impact location on the face of the club. Furthermore, the accuracy of conventional clubs is highly dependent on impact location.

Thus, there is a need for a golf club head with a hitting face that maximizes golf ball travel distance while maintaining golf ball landing accuracy.

SUMMARY OF THE INVENTION

The present invention relates to a golf club head adapted for attachment to a shaft. The head includes a face and a body. The face is configured and dimensioned so that it includes a central portion and an adjacent surrounding intermediate portion. The central portion is relatively rigid and the intermediate portion is relatively flexible so that upon ball impact, the intermediate portion of the face deforms to provide high ball velocity, while the central portion is substantially un-deformed so that the ball flies on-target. Thus, upon ball impact the deformation of the intermediate portion allows the central region to move into and out of the club head as a unit. As a result, the head exhibits a coefficient of restitution greater than 0.81.

The above is accomplished by providing the central portion with a first flexural stiffness and the intermediate portion with a second flexural stiffness. Flexural stiffness is defined as Young's modulus or elastic modulus (E) times the portion's thickness (t) cubed or Et^3. The first flexural stiffness is substantially different from the second flexural stiffness. As a result, upon ball impact, the intermediate portion exhibits substantial deformation so that the central portion moves into the club head, and the central portion exhibits minimal deformation.

In one embodiment, the first flexural stiffness is at least three times the second flexural stiffness. In other embodiments, the first flexural stiffness is six to twelve times the second flexural stiffness. More preferably, the first flexural stiffness is greater than 25,000 lb-in. Most preferably, the first flexural stiffness is greater than 55,000 lb-in. Preferably, the second flexural stiffness is less than 16,000 lb-in. More preferably, the second flexural stiffness is less than 10,000 lb-in.

Since the flexural stiffness is a function of material and thickness, the following techniques can be used to achieve the substantial difference between the first and second flexural stiffness: 1) different materials can be used for each portion, 2) different thicknesses can be used for each portion, or 3) different materials and thicknesses can be used for each portion. For example, in one embodiment, the thickness of the central portion is greater than the thickness of the intermediate portion and the material for both portions is the same, e.g., titanium or steel.

The golf club head further includes a perimeter portion disposed between the intermediate portion and the body of the club. In one embodiment, the perimeter portion has a third flexural stiffness that is at least two times greater than the second flexural stiffness. The area of the perimeter portion preferably comprises less than 30% of the total area of the club head face.

In an alternative embodiment, a golf club head includes a shell that defines an inner cavity and a face. The face defines a face area and includes a first portion in the center and a second portion adjacent thereto. The first portion has a first thickness and defines a first area. The second portion has a second thickness. The first area is between about 15% and about 60% of the total face area, and the first thickness is greater than the second thickness. More preferably, the first area is between about 20% and 50% of the face area. The shell further includes a top crown portion and a spaced-apart sole plate, a heel portion and a spaced toe portion, and a rear spaced from the face.

In the club heads discussed above, the first, second, and third portions can have various shapes, such as the shape of the face or an elliptical shape. Furthermore, the club head inner cavities can have a volume greater than about 250 cubic centimeters, and more preferably a volume greater than about 275 cubic centimeters. It is preferred that the face of the club head has a loft of less than about 13°.

In addition, the central, intermediate, and perimeter portions can each have variable thicknesses.

Another feature of the present invention is locating the center of gravity of the club head with respect to a Cartesian coordinate system. The origin of the Cartesian coordinate system preferably coincides with the geometric center of the hitting face. The X-axis is a horizontal axis positioned tangent to the geometric center of the hitting face with the positive direction toward the heel of the club. The Y-axis is another horizontal axis orthogonal to the X-axis with the positive direction toward the rear of the club. The Z-axis is a vertical axis orthogonal to both the X-axis and Y-axis with the positive direction toward the crown of the club. The center of gravity is preferably located behind and lower than the geometric center of the face.

In one embodiment, the center of gravity is spaced from the geometric center along the Z-axis by a first distance of at least about 0.1". More preferably, the center of gravity is spaced from the geometric center along the Z-axis toward the sole plate, wherein the first distance is at least about 0.15". In another embodiment, the center of gravity is spaced a second distance from the geometric center along the

X-axis, wherein the second distance is less than about 0.02". In addition, the center of gravity is spaced a third distance from the geometric center along the Y-axis toward the rear portion, wherein the third distance is less than about 1.25".

The present invention is also directed to a golf club head having a hitting face and adapted for attachment to a shaft. The face includes a total face area and first primary resonant frequency, which is preferably less than about 2900 Hz. The face further includes a central zone that includes a geometric center of the face, and an intermediate zone disposed adjacent the central zone. The central zone has a first flexural stiffness and a central zone area that is at least 15% of the total face area. The intermediate zone has a second flexural stiffness. The first flexural stiffness is at least 25,000 lb-in and greater than the second flexural stiffness.

An embodiment of the present invention is directed to a golf club head adapted for attachment to a shaft and having a hitting face, wherein the hitting face comprises a directional control portion, said directional controlled portion comprises two or more zones having different flexural stiffness, such that when the hitting face impacts a golf ball the zones exhibit different degrees of deformation to selectively control the direction of the flight of the golf ball. The hitting face may further include a central portion disposed within the directional control portion, which contains a geometric center of the hitting face, and the flexural stiffness of the central portion is at least about three times, preferably at least about six times and more preferably at least about twelve times, greater than the flexural stiffness of the directional control portion.

The golf club head may further have a perimeter portion disposed around the directional control portion, wherein the flexural stiffness of the perimeter portion is at least about two times greater than the flexural stiffness of the directional control portion. In accordance to one aspect, the flexural stiffness of a first zone of said two or more directional control zones is between about 8,500 lb·in to about 60,000 lb·in. The flexural stiffness of a second zone of said two or more zones is about 0.5 time to about two times the flexural stiffness of the first zone. Furthermore, the flexural stiffness of a third zone of said two or more zones is about 0.7 times to about 1.3 times the flexural stiffness of the first zone, and the flexural stiffness of a fourth zone of said two or more zones is about 0.7 times to about two times the flexural stiffness of the first zone.

The directional control portion may comprise an upper crown zone and a lower heel zone, or may comprise a lateral heel zone and a lateral toe zone. Alternatively, the directional control portion may comprise all four of these zones. Preferably, these four zones are delineated by a vertical center line and a horizontal center line of the hitting face.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred features of the present invention are disclosed in the accompanying drawings, wherein similar reference characters denote similar elements throughout the several views, and wherein:

FIG. 1 is a toe side, front, and perspective view of a first embodiment of a golf club head of the present invention;

FIG. 2 is a heel side, rear, and perspective view of the golf club head of FIG. 1;

FIG. 3 is a front, elevational view of the golf club head of FIG. 1;

FIG. 3A is a cross-sectional view of the face of the golf club head of FIG. 3 along line 3A—3A;

FIG. 3B shows a cross-sectional view the face of the golf club head of FIG. 3 along line 3B—3B;

FIG. 4 is a top view of the golf club head of FIG. 1;

FIG. 5 is a bottom, perspective view of the golf club head of FIG. 1;

FIG. 6 is a toe side, front, and perspective view of a second embodiment of a golf club head of the present invention;

FIG. 7 is a front, elevational view of the golf club head of FIG. 6;

FIG. 7A is a cross-sectional view of the face of the golf club head of FIG. 7 along line 7A—7A;

FIG. 7B shows a cross-sectional view the face of the golf club head of FIG. 7 along line 7B—7B;

FIG. 8 is a toe side, front, and perspective view of a third embodiment of a golf club head of the present invention;

FIG. 9 is a front, elevational view of the golf club head of FIG. 8;

FIG. 9A is a cross-sectional view of the face of the golf club head of FIG. 9 along line 9A—9A;

FIG. 10 is a toe side, front, and perspective view of a fourth embodiment of a golf club head of the present invention;

FIG. 11 is a front, elevational view of the golf club head of FIG. 10;

FIG. 11A is a cross-sectional view of the face of the golf club head of FIG. 11 along line 11A—11A;

FIG. 12 is an enlarged, front view of a golf club head with ultrasonic thickness measurement locations indicated;

FIG. 13 is a schematic representation of the apparatus for taking an ultrasonic thickness measurement on the face of a club head;

FIG. 14 is an enlarged, elevational view of a portion of the face of a laminated golf club head of the present invention;

FIG. 15 is a schematic representation of a testing apparatus for obtaining frequency response data from a club head;

FIG. 15A is a perspective view of an attached mass for use with the testing apparatus of FIG. 15;

FIG. 16 is a graph of inertance versus frequency for a conventional club head;

FIG. 17 is a graph of inertance versus frequency for the inventive club head;

FIG. 18 is a graph of COR versus face thickness for two alternative titanium alloys;

FIG. 19 is a graph of COR versus first resonant frequency for two alternative titanium alloys;

FIGS. 20–23 are front, elevational views of another embodiment in accordance to the present invention; and

FIGS. 24–26 are perspective and front, elevational views of another embodiment in accordance to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIGS. 1–5, a first embodiment of a golf club head 10 of the present invention is shown. Club head 10 includes shell 12 with body 14, hitting face 16, toe portion 18, heel portion 20, sole plate 22, hosel 24, bottom portion 26, crown portion 28, and rear portion 29. The sole plate 22 fits in a recess 30 (as shown in FIG. 5) in the bottom portion 26 of body 14. The shell 12 and sole plate 22 create an inner cavity 31 (as shown in FIG. 5). The hitting face 16 has an exterior surface 32 and an interior surface 34. The exterior surface 32 may optionally have grooves 35.

A golf club shaft (not shown) is attached at hosel 24 and is disposed along a shaft axis SHA. The hosel may extend to the bottom of the club head, may terminate at a location between the top and bottom portions of the head, or the hosel can terminate flush with the top portion and extend into the cavity in the head.

Inner cavity 31 of club head 10 may be empty, or alternatively may be filled with foam or other low specific gravity material. It is preferred that the inner cavity 31 has a volume greater than 250 cubic centimeters, and more preferably greater than 275 cubic centimeters. Preferably, the mass of the inventive club head is greater than 150 grams but less than 220 grams.

Referring to FIGS. 3–3B, the face 16 includes a central zone or portion 36, an intermediate zone or surrounding portion 38 adjacent the central zone 36, and an optional perimeter zone or outer portion 40. The intermediate zone 38 preferably surrounds central zone 36, and the perimeter zone 40 preferably surrounds the intermediate zone 38. The perimeter zone 40 is located between the intermediate zone 38 and crown portion 28. In the following specification and claims, the central zone 36 is a contiguous zone centrally located on the hitting face 16 and containing a geometric center ("GC") of the hitting face.

Zones 36, 38 and 40 have a shape that is similar to the shape of hitting face 16 only with a smaller area, as discussed in detail below. Preferably, zones 36, 38 and 40 are substantially concentric to each other within hitting face 16. The central zone 36 has a first thickness t_1. The intermediate zone 38 has a second thickness t_2. The first thickness t_1 is greater than the second thickness t_2. Typically, when the club head is cast, the perimeter zone 40 will be thicker than the intermediate zone 38. However, the present invention is not limited to this configuration. Preferably, the first thickness t_1 is equal to about one and a half (1.5) times the thickness t_2 to about four (4) times the thickness t_2 of the intermediate zone 38.

The thickness relationships between the zones 36, 38, and 40 are provided so that a predetermined relationship exists between flexural stiffness exhibited by each of the zones. Flexural stiffness (FS) of each zone is defined by the following simplified formula:

$$FS=Et^3$$

where,

E=the elastic modulus or Young's modulus of the material of the zone; and

t=the thickness of the zone.

The central zone 36 has a first flexural stiffness FS_1. The intermediate zone 38 has a second flexural stiffness FS_2. The perimeter zone 40 has a third flexural stiffness FS_3. The predetermined relationship between the portions is that the first flexural stiffness FS_1 is substantially greater than the second flexural stiffness FS_2, and optionally the third flexural stiffness FS_3 is substantially greater than the second flexural stiffness FS_2. Preferably, the first flexural stiffness FS_1 is at least three times greater than the second flexural stiffness FS_2. As a ratio the following relationship must be satisfied:

$$(FS_1/FS_2)\geq 3.$$

This expression means that the ratio of the central zone flexural stiffness FS_1 to the intermediate zone flexural stiffness FS_2 is equal to or greater than 3.0. When the above ratio of flexural stiffness is less than three, the central zone sustains excessive deformation during impact and accuracy

of the club is diminished. More preferably, the first flexural stiffness FS_1 is at least six to twelve times greater than the second flexural stiffness FS_2. Most preferably, the first flexural stiffness FS_1 is about eight times greater than the second flexural stiffness FS_2.

Preferably, the third flexural stiffness FS_3 is at least two times greater than the second flexural stiffness FS_2. Thus, the following relationship must be satisfied:

$$(FS_3/FS_2) \geq 2.$$

In club head **10** (as shown in FIG. **3**), the above flexural stiffness relationships are achieved by selecting a certain material with a particular elastic modulus and varying the thickness of the zones. In another embodiment, the flexural stiffness relationships can be achieved by varying the materials of the zones with respect to one another so that the zones have different elastic moduli and the thickness is changed accordingly. Thus, the thickness of the portions can be the same or different depending on the elastic modulus of the material of each portion. It is also possible to obtain the required flexural stiffness ratio through the use of structural ribs, reinforcing plates, and thickness parameters.

Quantitatively, it is preferred that the first flexural stiffness FS_1 is greater than 20,000 lb-in. When the first flexural stiffness is less than 20,000 lb-in excessive deformation of the central region can occur during impact and accuracy is diminished. More preferably, the first flexural stiffness FS_1 is greater than 55,000 lb-in. Preferably, the second flexural stiffness FS_2 is less than 16,000 lb-in. When the second flexural stiffness is greater than 16,000 lb-in the COR the resultant ball velocity is reduced. More preferably, the second flexural stiffness FS_2 is less than 10,000 lb-in and, most preferably, less than 7,000 lb-in.

Referring to FIG. **3**, it is preferred that central portion **36** has a first area that is between about 15% and about 60% of the exterior surface area **32** or face area. The percentage of face area is computed by dividing the area of each zone **36**, **38**, or **40** by the total face area of exterior surface **32**. It should be noted that the total face area of the exterior surface **32** is equivalent to the sum of areas of the zones **36**, **38**, and **40**. In a preferred embodiment, the central zone first area is greater than about 15% and less than about 60% of the total face area. When the central zone **36** is less than 15% of the total face area, then accuracy can be diminished. When central portion **36** is greater than 60% of the face area **32**, then COR can be diminished.

Referring again to FIG. **1**, the club head **10** is further formed so that a center of gravity of the club head has a predetermined relationship with respect to a Cartesian coordinate system with a center located on the exterior surface and coincident with the geometric center GC of the face **16**. The face includes a vertical centerline VCL and a horizontal centerline HCL perpendicular thereto. The geometric face center GC is at the intersection of these centerlines VCL and HCL. Preferably, the geometric center of the central zone **36** is coincident with the club face geometric center GC.

The Cartesian coordinate system is defined when the club head is resting on a flat surface (i.e., at its natural loft) and includes three axes, as illustrated in FIG. **1**. The origin of the Cartesian coordinate system preferably coincides with the geometric center of the hitting face. The X-axis is a horizontal axis positioned tangent to the geometric center of the hitting face with the positive direction toward the heel of the club. The Y-axis is another horizontal axis orthogonal to the X-axis with the positive direction toward the rear of the club. The Z-axis is a vertical axis orthogonal to both the X-axis and Y-axis with the positive direction toward the crown of the club. The center of gravity is preferably located behind and lower than the geometric center of the face.

Referring to FIG. **1**, the location of the center of gravity is defined by coordinates for the center of gravity CG_z, CG_y, and CG_x with respect to the Z, X, and Y axes, respectively. In the vertical direction along the Z-axis, the center of gravity coordinate is designated CG_z, and is spaced a first distance D1 from the geometric face center G along the Z-axis. The first distance D1 is at least about −0.1 inches, and more preferably the first distance D1 is at least about −0.15 inches so that the center of gravity in the vertical direction is below the geometric center GC.

In the horizontal direction along the X-axis, the center of gravity coordinate is designated CG_x, and is spaced a second distance D2 from the geometric face center GC. The second distance D2 is less than about 0.02 inches and greater than −0.02 inches so that the center of gravity in the horizontal direction is spaced from the center GG by no further than the magnitude of distance D2.

Referring to FIG. **1**, along the Y-axis, the center of gravity coordinate is designated CG_y, and is spaced a third distance D3 from the geometric face center GC preferably toward the rear portion **29**. The center of gravity CG_y in the third direction is spaced from the center GC toward the rear portion **29** by no further than the magnitude of the third distance D3. The third distance D3 is preferably equal to or less than about 1.25 inches and, more preferably, less than about 1 inch.

EXAMPLES

These and other aspects of the present invention may be more fully understood with reference to the following non-limiting examples, which are merely illustrative of embodiments of the present invention golf club head, and are not to be construed as limiting the invention, the scope of which is defined by the appended claims.

TABLE 1

FLEXURAL STIFFNESS INFORMATION

Parameter	Comparative Example 1	Comparative Example 2	Comparative Example 3	Inventive Example
Thickness of Center Zone (inches)	0.115	0.130	0.095	0.150
Thickness of First Intermediate Zone (inches)	0.115	0.100	0.098	0.075
Thickness of Second Intermediate Zone (inches)	0.115	0.080	0.100	0.075
Thickness of Perimeter Portion (inches)	0.115	0.150	0.120	0.120
E of All Portions (psi)	1.65E+07	1.65E+07	1.65E+07	1.65E+07
FS of Center Portion (lb-in)	25094	36251	14147	55688
FS of First Intermediate zone (lb-in)	25094	16500	15530	6961
FS of Second Intermediate Zone (lb-in)	25094	8448	16500	6961
FS of Perimeter Zone (lb-in)	25094	55688	28512	28512
FS_1/FS_2	1.0	2.2	0.9	8.0
FS_3/FS_2	1.0	3.4	1.8	4.1

Comparative Examples 1–3 are club heads configured and dimensioned as indicated above with materials so that the zones have certain values. As a result, the ratio of the central

zone flexural stiffness and adjacent intermediate zone flexural stiffness for the Comparative Examples are 1.0, 2.2, and 0.9. These ratios are outside of the preferred ratio that ($FS_1/FS_3 \geqq 3$) in accordance to one aspect of the present invention. On the other hand, the Inventive Example is configured and dimensioned so that (FS_1/FS_3=about 8). In the examples above, the intermediate zone is defined by a first intermediate zone adjacent the central zone and a second intermediate zone adjacent the first intermediate zone. The perimeter zone is adjacent the intermediate zone(s).

Comparative Examples 1 and 3 have a ratio of FS_3/FS_2 of 1.0 and 1.8, respectively. These ratios are also outside of the preferred ratio ($FS_3/FS_2 \geqq 2$) in accordance to another aspect of the present invention. Comparative Example 2 and the Inventive Example satisfy such a ratio with values of about 3.4 and 4.1, respectively.

TABLE 2

CENTER OF GRAVITY INFORMATION

Parameter	Comparative Example 1	Comparative Example 2	Comparative Example 3	Inventive Example
CG_z Location (inches)[1]	0.074	0.074	0.074	−0.120
CG_x Location (inches)[2]	0.133	0.137	0.137	−0.001
CG_y Location (inches)[3]	1.159	1.159	1.182	0.991

[1]Positive z is toward the crown from GC
[2]Positive x is toward the toe from GC
[3]Positive y is toward the back from the GC

The center of gravity for the Inventive Example club head was achieved by the configuration and dimensions of the club head in additional to adding a weight of 31.5 grams to the sole plate. Other known methods of weight manipulation can be used to achieve the inventive center of gravity location as set forth above.

Thus, referring to FIG. 1, in the club head example of the present invention the center of gravity is preferably located along the Z-axis at least 0.10 inches below the geometric face center GC, along the X-axis within 0.01 inches from the geometric face center GC, and along the y-axis within 1.25 inches from the geometric face center GC. The Parameter column of Table 2 describes for each center of gravity location or coordinate the distance that the center of gravity is spaced from the face geometric center GC with respect to a Cartesian coordinate system along particular axes. The centers of gravity for Comparative Examples 1–3 are not located properly with respect to the inventive requirements along the Z- and X-axes. The center of gravity for the Inventive Example is located properly with respect to the inventive requirements in the Z, X, and Y axes.

TABLE 3

TEST RESULTS

Parameter	Comparative Example 1	Comparative Example 2	Comparative Example 3	Inventive Example
Maximum COR	0.807	0.808	0.829	0.830
Average COR	0.765	0.766	0.783	0.789
Maximum Total Distance (yards)	290	286	291	298
Landing Area ($yards^2$)	950	255	1000	341

The test results enumerated in Table 3 were generated using computational techniques, which included finite element analysis models. When computer modeling the exemplary club heads, the following assumptions were made: club head loft of 8.5°; club head mass of 201 grams; and club head material is 6AL-4V titanium alloy. The golf ball used was a two-piece solid ball. Finite element models were used to predict ball launch conditions and a trajectory model was used to predict distance and landing area. The impact condition for the swing used in the total distance and landing area predictions or tests had a club head velocity of 109.1 mph and an attack angle of +2 degrees, the club was oriented such that the vertical plane of the face was at an angle of 8.5 degrees relative to the velocity vector. The impact condition used for club coefficient of restitution (COR) tests was consistent with the USGA Rules for Golf, specifically, Rule 4-1e Appendix II Revision 2 dated Feb. 8, 1999.

COR or coefficient of restitution is one way of measuring ball resiliency. The coefficient of restitution (COR) is the ratio of the velocity of separation to the velocity of approach. In this model, therefore, COR was determined using the following formula:

$$(v_{club\text{-}post} - v_{ball\text{-}post})/(v_{ball\text{-}pre} - v_{club\text{-}pre})$$

$v_{club\text{-}post}$ represents the velocity of the club after impact;
$v_{ball\text{-}post}$ represents the velocity of the ball after impact;
$v_{club\text{-}pre}$ represents the velocity of the club before impact (a value of zero for USGA COR conditions); and
$v_{ball\text{-}post}$ represents the velocity of the ball before impact.

COR, in general, depends on the shape and material properties of the colliding bodies. A perfectly elastic impact has a COR of one (1.0), indicating that no energy is lost, while a perfectly inelastic or perfectly plastic impact has a COR of zero (0.0), indicating that the colliding bodies did not separate after impact resulting in a maximum loss of energy. Consequently, high COR values are indicative of greater ball velocity and travel and total distance. Club heads with thinner faces also have higher COR values, as exhibited by Comparative Example 3 as compared to the Comparative Club 1. However, unexpectedly the Inventive Example has the highest COR. For the inventive club head, preferably the COR is greater than about 0.81, and more preferably greater than about 0.83.

It is expected that as COR increases the ball flight distance will increase and the maximum total distance will also increase. The Inventive Example has the highest COR and also the highest maximum total distance.

It as also expected that as COR increases the shot accuracy will decrease. However, the Inventive Example has the highest COR and the greatest accuracy as illustrated by the data for Landing Area. The Landing Area is an area encompassing the position of nine balls, which impact the club face at various locations. The nine impact locations were equally spaced within a rectangular region 1 inch wide and 0.5 inches high, centered on the geometric center of the club face. The club head of the Inventive Example has a very small Landing Area of 341 square yards. The Comparative Example 3, which is the only Comparative Example with a sufficient COR of at least 0.81, has a Landing Area of 1000 square yards, which is significantly greater than the Landing Area for the Inventive Club. The smaller the landing area, the greater the accuracy of the club.

Several alternative embodiments of the invention are possible. The features of the invention include flexural stiffness for distinct zones or portions of the club face, as well as the ratio of flexural stiffness between portions. A wide variety of rib configurations and material alternatives

may be used to attain the requisite flexural stiffness and flexural stiffness ratio of the face portions.

In FIGS. 3–3B, a preferred embodiment of the club **10** is shown. The club **10** has a face **16** with the following construction. The central zone **36** has a thickness, t_1, of about 0.150 inches, the intermediate zone **38** has thickness, t_2, of about 0.075 inches, and the perimeter zone **40** has thickness, t_3, of about 0.120 inches. Furthermore, the central zone **36** comprises about 20% of the total face surface area and the perimeter zone **40** is less than about 20% of the total face surface area. Each of the three zones **36**, **38**, and **40** has uniform thickness within the zone and are constructed from a single homogeneous material, preferably a titanium alloy, with a Young's modulus (E) of approximately 16.5×10^6 lbs/in^2.

Referring to FIGS. 3–3B, the flexural stiffness, FS_z, can also be defined by the following general equation:

$$FS_z = \sum_{i=1}^{n} \frac{A_i}{\sum_{j=1}^{n} A_j} E_i t_i^3$$

where;

A_i is defined as the area of a constituent within a zone,

E_i is the Young's modulus in pounds per square inch of the constituent within a zone,

$$\sum_{j=1}^{n} A_j$$

represents the total area of the zone,

t_i is the thickness or average thickness in inches of a constituent within a zone,

n is the number of constituents within a zone.

This general equation reduces to the simplified equation $FS_z=Et^3$, stated above when each zone has a uniform thickness and a constant Young's modulus.

Using this simplified equation, the flexural stiffness can be calculated for the central and abutting zones and the flexural stiffness ratio can be computed. The flexural stiffness ratio for the preferred embodiment golf club head **10** is calculated as,

$$FS_c = E_c t_c^3 = (16.5\times10^6 \text{ lb/in}^2)(0.15 \text{ in})^3$$
$$= 55{,}689 \text{ lb·in, and}$$
$$FS_1 = E_1 t_1^3 = (16.5\times10^6 \text{ lb/in}^2)(0.075 \text{ in})^3$$
$$= 6{,}961 \text{ lb·in,}$$

where FS_c is the flexural stiffness of central region **36** (also denoted FS_1 as herein) and FS_1 is the flexural stiffness of intermediate region **38** (also denoted FS_2 as herein). These values are also reported in Table 1, above. Hence, the ratio of flexural modulus of golf club head **10** is

$(FS_c/FS_1)=8.0$.

In FIG. **6**, an alternate embodiment of the club head **110** is shown to illustrate an alternate construction of hitting face **116** that results in a similar flexural stiffness ratio of the central portion to the abutting intermediate zone as the embodiment of FIG. **3**. In the club head **110**, the face **116** has an elliptically shaped central zone **136** an adjacent intermediate zone **138**. The central zone **136** occupies about 30 percent of the total face surface area.

Referring to FIGS. **7–7B**, the central zone **136** includes a ribbed support structure **137***a* (shown in phantom) that extends from the interior surface of the face. The asterisk-shaped ribbed structure, which comprises a plurality of ribs or legs, stiffens the central zone. The thickness of the ribbed portion **137***a* of the central zone t_{1A} is about 0.225 inches. The width of the rib, w, is about 0.085 inches. The thickness of the remaining portion **137***b* between the ribs of the central zone t_{1B} is about 0.09 inches. The ribbed structure **137***a* is defined such that it comprises about 25 percent of the surface area of the central zone. The intermediate zone **138** has a uniform thickness, t_2, of about 0.075 inches and extends to the boundary of the face **116** with no defined perimeter zone. The face **116** is preferably made of a homogeneous titanium alloy with a Young's modulus (E) of 16.5×10^6 lbs/in^2.

Referring to FIGS. **6–7B**, the flexural stiffness ratio between the central region **136** and the abutting intermediate zone **138** is computed, as follows:

Area of the elliptical central region **136** is $A_C=\pi\times b\times a$, where "b" is ½ of the major axis of the ellipse and "a" is ½ of the minor axis of the ellipse. When the major axis is 2 inches and the minor axis is 1 inch, the area of the central region is 1.57 in^2.

The area of the ribs is simply its width (WI=0.085 inch) times its length (LI=4.6 inch) or A_r=WI×LI=0.39 in^2.

Hence, the non-rib area $A_{NR}=A_c-A_r=(1.57-0.39)=1.18$ in^2.

Thus, the general flexural stiffness equation stated above reduces to

$$FS_c = (A_r/A_c)E(t_{1A})^3 + (A_{NR}/A_C)E(t_{2B})^3,$$
$$FS_c = (0.39/1.57)(16.5\times10^6 \text{ lb/in}^2)(0.225 \text{ in})^3 +$$
$$(1.18/1.57)(16.5\times10^6 \text{ lb/in}^2)(0.090 \text{ in})^3,$$
$$FS_c = 56{,}008 \text{ lb·in, and}$$
$$FS_1 = E(t_2)^3,$$
$$= (16.5\times10^6 \text{ lb/in}^2)(0.075 \text{ in})^3,$$
$$= 6{,}961 \text{ lb·in.}$$

Hence, $(FS_c/FS_1)=8.05$.

It should be noted that ribs, welts, pimples, or other discrete thickness variations within a zone are handled as discrete elements within a particular zone and are computed in accordance with the governing general equation for flexural stiffness discussed above.

In FIG. **8**, an alternate embodiment of the club head **210** is shown to illustrate an alternate construction of face **216** that results in a similar flexural stiffness ratio of the central zone to the abutting intermediate zone as the embodiment of FIG. **3**. In the club head **210**, the face **216** has a central zone **236** and an adjacent intermediate zone **238**. The central zone **236** is about 30 percent of the total face surface area. The club head **210** does not have a defined perimeter zone.

Referring to FIGS. **9–9A**, the central zone **236** has a uniform thickness of t_1 of about 0.140 inches. The intermediate zone **238** has a continuously tapered thickness from the face perimeter inward to the central zone **236**. The thickness of the intermediate zone **238** is defined to change linearly.

The intermediate zone **238** has an inner thickness, t_{2d}, of about 0.07 inches at the boundary of the central zone **236**

and the intermediate zone **238**. The intermediate zone **238** has an outer thickness, t_{2B}, of about 0.10 inches. The outer thickness is at the face perimeter. In instances of non-uniform thickness, within a zone, and primarily in relation to a continuous tapered zone, an average thickness may be used to compute the flexural stiffness for the zone. This approximation simplifies the calculation and is physically based on elastic shell theory.

In this embodiment, two different homogenous materials are used. The central zone **236** is preferably made from a stainless steel having a Young's modulus of 30.0×10^6 lbs/in^2 and the adjacent intermediate zone **238** is made from a titanium alloy with a Young's modulus of 16.5×10^6 lbs/in^2.

Referring to FIGS. **8–9A**, the flexural stiffness ratio between the central and adjacent zone is computed.

$$FS_c = E_c(t_1)^3,$$
$$= (30\times10^6 \text{ lb/in}^2)(0.140 \text{ in})^3,$$
$$= 82{,}320 \text{ lb}\cdot\text{in},$$
$$FS_I = E_I((t_{2A}+t_{2B})/2)^3,$$
$$= (16.5\times10^6 \text{ lb/in}^2)((0.1+0.07)\text{in}/2)^3,$$
$$= 10{,}133 \text{ lb}\cdot\text{in}.$$

Hence, (FS_c/FS_I)=8.12.

In FIG. **10**, an alternate embodiment of the club head **310** is shown to illustrate an alternate construction of face **316** that results in a similar flexural stiffness ratio of the central zone to the abutting intermediate zone as the embodiment of FIG. **3**. In the club head **310**, the face **316** has an elliptically shaped central zone **336** and an adjacent intermediate zone **338**. The central zone **336** is formed using two materials **337***a* (shown in phantom) and **337***b* (shown in phantom).

The central zone **336** has a uniform thickness, t_1, of about 0.140 inches. The first material **337***a* is a titanium alloy with a Young's modulus of 16.5×10^6 lbs/in^2. The second material **337***b* is stainless steel and has a Young's modulus of 30×10^6 lbs/in^2. The central zone **336** comprises about 60 percent stainless steel.

Furthermore, the central zone **336** is elliptically shaped and comprises about 25 percent of the total face surface area. The intermediate zone **338** with the perimeter zone **340** comprises of no more than 20 percent of the total face surface area. The intermediate zone has a uniform thickness, t_2, of about 0.08 inches and is constructed from the same titanium alloy as the central zone **336**.

Referring to FIGS. **10–11A**, the flexural stiffness ratio between the central region **336** and intermediate zone **338** can be computed, as follows.

Using the equation for determining the area for an ellipse, stated above, when the major axis is about 1.8 inch and the minor axis is about 0.9 inch, the area of central region **336** is A_C=1.272 in^2. As discussed above, the area of stainless steel (A_S) is 60 percent and the area of titanium or non-steel (A_{NS}) is 40 percent.

$$FS_c = (A_s/A_c)E_s(t_1)^3 + (A_{NS}/A_C)E_t(t_1)^3,$$
$$FS_c = (0.60)(30\times10^6 \text{ lb/in}^2)(0.14 \text{ in})^3 +$$
$$(0.40)(16.5\times10^6 \text{ lb/in}^2)(0.14 \text{ in})^3,$$
$$FS_c = 67{,}502 \text{ lb}\cdot\text{in, and}$$

-continued

$$FS_I = E_t(t_2)^3,$$
$$= (16.5\times10^6 \text{ lb/in}^2)(0.080 \text{ in})^3,$$
$$= 8{,}448 \text{ lb}\cdot\text{in}.$$

Hence, (FS_c/FS_I)=8.0.

The golf club head embodiments **10**, **110**, **210**, and **310** discussed in FIGS. **1–11A** demonstrate four unique face constructions which result in a similar flexural stiffness ratio, where the central zone to the adjacent zone ratio is greater than or equal to three and, more particularly, about eight. In cases where the face construction is uncertain due to manufacturing tolerances or methods or for other possible reasons, a nondestructive test method of determining the flexural stiffness ratio for a given face construction may be used.

Referring to FIG. **12**, a typical club **410** is shown with an unknown face thickness profile. Preferably, something is known regarding the construction materials of the face or has been determined experimentally through test methods known to those of ordinary skill in the art. In FIG. **12**, a random distribution of points is shown on face **416**. This distribution is referred to herein as a "point cloud" or predetermined point distribution. Points labeled C indicate a position in the central zone **436**. Points labeled I indicate a position in the intermediate zone **438**. Points labeled P indicate a position in the perimeter zone **440**. The numbers following the position letters "C", "I" or "P" indicate relative face position.

Using the defined point cloud, an ultrasonic measurement device **450** (as shown in FIG. **13**) can be used to map the face **416** thickness profile. The point cloud technique has the advantage of capturing discrete variations in face thickness such as the presence of ribs or abrupt thickness changes. One preferred ultrasonic measurement device includes a Panametrics Model 25DL ultrasonic thickness device **455** and a Panametrics model M208 probe **460**. The sensor or device **455** and the probe or transducer **460** are commercially available from Panametrics, Inc. of Waltham, Mass.

Referring to FIG. **12**, the face thickness data obtained from the ultrasonic measurement, along with material modulus information, is then used to define the central, intermediate and possibly perimeter zones. The central zone **436** is defined by constructing an area comprising of a specific percentage of the total face surface area and including the geometric center GC. The point cloud thickness data within the defined zone is then averaged or broken into distinct elements within the zone. If the latter is required, the area percentages for the elements within the zone are calculated. The calculation for FSz previously outlined is then carried out to determine the flexural stiffness ratio between the central and adjacent zone **436** and **438**, respectively.

The following example illustrates the technique. In Table 4, random face thickness measurements are shown for titanium alloy club **410** (as shown in FIG. **12**) with an unknown face thickness profile. The technique described above is used.

TABLE 4

ULTRASONIC FACE THICKNESS DATA

Position	Thickness	Position	Thickness	Position	Thickness
C1	0.132	I1	0.102	P1	0.110
C2	0.127	I2	0.103	P2	0.115
C3	0.131	I3	0.098	P3	0.117

TABLE 4-continued

ULTRASONIC FACE THICKNESS DATA

Position	Thickness	Position	Thickness	Position	Thickness
C4	0.125	I4	0.096	P4	0.119
C5	0.136	I5	0.088	P5	0.120
C6	0.130	I6	0.089	P6	0.114
C7	0.127	I7	0.089	P7	0.117
C8	0.129	I8	0.094	P8	0.109
C9	0.133	I9	0.097	P9	0.108
C10	0.138	I10	0.099	P10	0.111
C11	0.134	I11	0.100	P11	0.115
C12	0.131	I12	0.103	P12	0.118
		I13	0.106	P13	0.109
		I14	0.102	P14	0.108
		I15	0.105	P15	0.112
		I16	0.101	P16	0.112
		I17	0.100	P17	0.115
		I18	0.103	P18	0.109
		I19	0.107	P19	0.117
		I20	0.106	P20	0.120

FIG. 12 shows the measured data points and the projected central, intermediate and perimeter zones **436**, **438** and **440**. Based on these projected areas, the percentage of each zone can be estimated or computed more accurately by other techniques, such as face scanning. The data defines three zones, the actual central zone with an average thickness of 0.131 inches; the actual intermediate zone with an average thickness of 0.099 inches, and the perimeter zone with an average thickness of 0.114 inches. Furthermore, the area of the central zone has been estimated to be about 23 percent of the total face surface area, and the perimeter zone is estimated to comprise of about 35 percent of the total face area. Based on this information a flexural stiffness ratio can be computed at set forth below.

With regard to the calculation of face flexural stiffness and the flexural stiffness ratio, the aforementioned embodiments and point cloud example all consider hitting faces, which possess isotropic material property and symmetry with regard to a mid-surface of the face structure. Material isotropy, however, is not necessary condition of the invention. And the invention can include club heads with anisiotropic materials. The flexural stiffness or the flexural stiffness ratio can be used with ansiotopic constructions. These calculations would still be applicable but of a more general form, as discussed below.

The notion of symmetry with regard to a mid-surface of the face simplifies the calculations of flexural stiffness. The calculation of flexural stiffness for asymmetric shell structures with respect to the mid-surface is common in composite structures where laminate shell theory is applicable. Here the Kirkhoff shell assumptions are applicable. Referring to FIG. **14**, an asymmetric isotropic laminate **500** is shown with N lamina or layers **502**. Furthermore, the laminate is described to be of thickness, t, with x_i being directed distances or coordinates in accordance with FIG. **14**. The positive direction is defined to be downward and the laminate points x_i defining the directed distance to the bottom of the k^{th} laminate layer. For example, x_0=−t/2 and x_N=+t/2 for a laminate of thickness t made comprised of N layers.

Further complexity is added if the lamina can be constructed of multiple materials, M. In this case, the area percentage, Ai is included in the flexural stiffness calculation, as before in a separate summation over the lamina. The most general form of computing the flexural stiffness in this situation is, as stated above:

$$FS_z = \sum_{i=1}^{n} \frac{A_i}{\sum_{j=1}^{n} A_j} E_i t_i^3$$

Due to the geometric construction of the lamina about the mid-surface, asymmetry results, i.e., the laminate lacks material symmetry about the mid-surface of the laminate. However, this asymmetry does not change the calculated values for the flexural stiffness only the resulting forces and moments in the laminate structure under applied loads. An example of this type of construction would be a titanium alloy face of uniform thickness and first modulus E_t, where the central zone is backed by a steel member of width half the thickness of the titanium portion, and having second modulus E_s. In this example, the flexural stiffness can be approximated by the simplified equation, as follows:

$$FS_z = \frac{1}{3}\sum_{i=1}^{M}\left[E(x_i^3 - x_{i-1}^3)\right]_i$$

$$FS_z = 1/3\{[E_s(x_0^3 - x_1^3)] + E_t(x_1^3 - x_2^3)]\}$$

here, x_o=−t/2, x_1=t/2−WI and x_2=t/2, substitution yielding

$$FS_z = 1/3\{[E_s((-t/2)^3 - (t/2 - WI)^3)] + E_t[(t/2 - WI)^3 - (t/2)^3)]\}$$

If t=0.125, then WI=0.083 and FS of this zone is 3,745 lb·in, where the thickness of the steel layer is about one-half of the thickness of the titanium layer.

Referring to FIG. **15**, a testing apparatus **650** for measuring inertance is schematically illustrated. Generally, inertance is a frequency response. More specifically, inertance is a measure of the stiffness of a structure, in this instance the club face, at various frequencies of vibration. The units of inertance are acceleration units over force units. A preferred first resonant frequency for the inventive face is located where the inertance is maximized.

The test apparatus **650** includes club head **652**, a rigid mass **654**, an accelerometer **656**, and an impact hammer **658**. The mass **654** is preferably a cylindrical steel rod with a diameter of 1 inch. Referring to FIGS. **15** and **15A**, the mass **654** preferably has a cylindrical cavity **659** at one end for receiving the accelerometer **656** and a slot **660** to accommodate the cable **662**. The accelerometer **656** is connected to the geometric center of the face of the club head **652** with a high modulus adhesive **657**, such as a cyanoacrylate based adhesive, Loctite **409**, available from Loctite Corp., Newington, Conn. The mass **654** is then placed over the accelerometer **656** and also secured to the club face with cyanoacrylate adhesive. The combined mass of the mass **654** and the accelerometer **656** should equal the mass of a golf ball or 1.62 oz. The impact hammer **658** has an integral force transducer **658***a* and is movable toward and away from the free end **654***a* of the rigid mass, as indicated by the arrow I, to impact the mass **654**, which is attached to the club head face at the geometric center. The impact force or excitation force is normal to the club face, and upon impact is transmitted to the hitting face through the mass **654**.

The testing apparatus **650** further includes a junction box and ICP power supply **660** and cables **662** electrically connected to the accelerometer **656** and the impact hammer

transducer **658***a*. The junction box and ICP power supply **660** is in turn connected to a digital signal processing board **664**, located within a computer **665** with signal processing software **667**. The digital signal processing board **664**, computer **665** and software **667** are used to condition frequency signals and calculate the frequency response functions. The accelerometer **656**, transducer **658***a*, junction box and ICP power supply **660**, cables **662**, digital signal processing board **664**, computer **665**, and software **667** are commercially available and one of ordinary skill in the art can readily identify and obtain inertance values for golf clubs using these components. Typically, the data from 20 impacts are averaged to reduce noise and improve measurement accuracy. The following TABLE 5 lists specific model numbers for the vibration equipment shown in FIG. **13**.

TABLE 5

VIBRATION EQUIPMENT

Reference Number	Part	Model #	Supplier
656	Accelerometer	352A10	Modal Shop of Cincinnati, OH
658	Impact Hammer	086C01	Modal Shop
662	Cables	002T01	Modal Shop
660	Junction Box & ICP power	BNC 2140	National Instruments of Dallas, TX
664	DSP Board	NI 4551	National Instruments
665	Computer	Dell Optiplex Gxi	Dell Computers of Round Rock, TX
667	Software	Virtual Bench DSA 2.5.1	National Instruments

Referring to FIG. **16**, a graph of inertance versus frequency for a conventional club head is shown. The conventional club head is a Callaway Great Big Bertha War Bird with an eight degree loft. The inertance I shown is the result of testing using apparatus **650** of FIG. **15**. The point I_1 at a frequency of 3330 Hertz represents the first primary resonant frequency, which occurs at the first primary maxima inertance for the inertance function I. A maxima, which does not represent a primary resonant natural frequency of the face, is also present in FIG. **16** at a frequency of 2572 Hertz, which is the point I_2. These secondary maxima I_2 are characterized by inertance transitions of a magnitude of less than 10 decibels. These secondary maxima may be due to crown, sole or skirt vibrations that are not acting perpendicular to the plane of the club face. Secondary maxima do not correlate with COR and ball velocity, since the vibration response is either small in magnitude or alternately not coincident with ball response. The COR for the conventional club head tested was measured in accordance with USGA, Rule 4-1e Appendix II Revision 2 dated Feb. 8, 1999 and was found to be 0.785. The preferred first primary resonant frequency of vibration is defined by the following relationship:

$$1/(2\times\text{contact duration}) < f_1 < 3/(2\times\text{contact duration})$$

The contact duration is the time interval during which the ball is in contact with the club face. The contact duration for a typical driver impact is about 500 microseconds (500×10^{-6} second). Thus, the preferred primary resonant frequency of vibration for the club head is between about 1000 and 3000 Hz. The closer the contact time is to the lower limit, the higher the COR and thus the higher the rebound ball velocity. More preferably, the first primary resonant frequency is less than 2900 Hz.

FIG. **17** illustrates the inertance function of the inventive club head. The first primary resonant frequency is at 2632 Hz, and the COR of this inventive club was measured to be 0.824. The COR of the invention club is greater than the conventional club of FIG. **16**, and therefore will provide greater ball rebound velocity.

Several example club heads were produced with two commercially available titanium alloys 6AL-4V and SP700. The clubs were produced with a variety of uniform face thickness. FIG. **18** illustrates that as face thickness is reduced for a given titanium alloy the COR increases in a linear fashion. However, different titanium alloys with slightly different moduli have distinct trend lines and thickness alone is insufficient to predict COR. FIG. **19** illustrates a plot of COR versus first primary resonant frequency for the same set of club heads as those of FIG. **18**. FIG. **18** illustrates that first primary resonant frequency is predictive of COR regardless of titanium alloy. The first primary resonant frequency of a club head may be used as a quality control factor to ensure compliance with USGA COR rules.

In accordance to another embodiment of the present invention, hitting face **16** is divided into two or more non-concentric regions having distinct flexural stiffness as illustrated in FIGS. **20**–**23**. Club head **510** comprises toe **18**, heel **20**, sole plate **22**, hosel **24**, crown **28**, and back portions similar to the other inventive clubs described above. Club head **510** further has a hitting face **516** that comprises an upper or crown face portion **520** and a lower or sole face portion **522**. Club head **510** may also have an optional perimeter portion **540**. Preferably, the flexural stiffness of the crown face portion **520** is different than the flexural stiffness of the sole face portion **522**.

In accordance to one aspect, the flexural stiffness of crown face portion **520** is preferably about one half of the flexural stiffness of the sole face portion **522**. In other words, the flexural stiffness of hitting face **516** varies and more specifically increases in the direction from crown **28** to sole **22**. During an on-center or near center impact with a golf ball, as the hitting face deforms, crown face portion **520** deforms more than sole face portion **522** due to its lower flexural stiffness. This shift in the deformation causes a corresponding increase in launch angle of the golf ball, when compared to a similar golf club with a similar club loft angle but without the varying crown-to-sole flexural stiffness.

The increase in the launch angle of the golf ball achieved by the crown-to-sole flexural stiffness variation depends on a number of factors, including the location of the impacts on the hitting face and the flexural stiffness at the location of the impacts. Conversely, the launch angle of the golf ball can be reduced by reversing the crown-to-sole flexural stiffness variation, i.e., the flexural stiffness of the crown face portion **520** is higher than the flexural stiffness of the sole face portion **522**. In this embodiment, the launch angle decreases because the sole face portion deforms more than the crown face portion.

Preferably, the flexural stiffness (Et^3) for the crown face portion **520** of hitting face **516** is between about 8,500 lb·in and about 60,000 lb·in, and the flexural stiffness of the sole face portion **522** is about twice (200%) of the flexural stiffness of the crown face portion **520** or less, such that the launch angle of the golf ball increases. On the other hand, the flexural stiffness of the sole face portion is about one-half (50%) of the flexural stiffness of the crown face portion or more such that the launch angle of the golf ball decreases. Suitable ratios of flexural stiffness between these portions include 4::1, 1::4, 2::3 or 3::2.

In accordance to another aspect of the present invention, as illustrated in FIG. **21** hitting face **516** of club head **510** comprises heel face portion **524** and toe face portion **526**, such that the flexural stiffness of hitting face **516** varies in the heel-to-toe direction. Similar to the embodiment shown in FIG. **20**, this hitting face also selectively and locally deforms to direct the angle of the golf ball in a desirable lateral direction. More specifically, for on-center or near-center impacts when the flexural stiffness of heel face portion **524** is lower than the flexural stiffness of toe face portion **526**, the heel face portion deforms more to direct the angle of the ball more to the left of a right-handed golfer's body to compensate a tendency to slice or hook the ball to the right. On the other hand, when the flexural stiffness of the toe face portion **526** is lower than the flexural stiffness of the heel face portion **524**, the toe face portion deforms more to direct the golf ball to the right of a right-handed golfer's body to compensate for a tendency to slice or hook the ball to the left.

Preferably, the flexural stiffness (Et^3) for the heel face portion **524** of hitting face **516** is between about 8,500 lb·in and about 60,000 lb·in, and the flexural stiffness of the toe face portion **526** is about twice (200%) of the flexural stiffness of the heel face portion **524** or less, such that the flight of the golf ball is directed to the left. On the other hand, the flexural stiffness of the toe face portion is about one-half (50%) of the flexural stiffness of the heel face portion or more such that the flight of the golf ball is directed to the right. Suitable ratios of flexural stiffness between these portions include 4::1, 1::4, 2::3 or 3::2.

In accordance to another aspect of the present invention, the advantages of the hitting face shown in FIG. **20** and in FIG. **21** can be realized in a single hitting face, as illustrated in FIG. **22**. Here, hitting face **516** comprises four portions: crown-heel portion **528**, crown-toe portion **530**, sole-toe portion **532** and sole-heel portion **534**. The flexural stiffness of hitting face **516** can vary in both the crown-to-sole and heel-to-toe directions. The flexural stiffness can either increase or decrease in either direction. Hence, the advantages of altering the vertical launch angle and the lateral direction of the flight of a golf ball can be realized on a single golf club head.

Preferably, the flexural stiffness of the crown-heel portion **528** is between about 8,500 lb·in and about 60,000 lb·in. The flexural stiffness of the crown-toe portion **530** is preferably about 70% to about 130% of the flexural stiffness of crown-heel portion **528**. The flexural stiffness of the sole-toe portion **532** is preferably about 50% to about 130% of the flexural stiffness of crown-heel portion **528**. The flexural stiffness of the sole-heel portion **534** is preferably about 70% to about 200% of the flexural stiffness of crown-heel portion **528**.

Alternatively, the hitting face **516** may comprise two or more non-concentric portions that make up any regular or irregular shape, such as the embodiment illustrated in FIG. **23**. Furthermore, the boundaries between the non-concentric regions do not have to be substantially horizontal or substantially vertical.

Another readily apparent advantage of this embodiment is that it can reduce the manufacturing costs for golf clubs. The flexural stiffness of the hitting face can be altered in accordance to the present invention to achieve the effect of multiple lofts for a given head club design having a fixed loft angle. Tooling for a single mold with various face cavity inserts can produce a family of club heads having varying effective loft angles, albeit with a same exterior loft angle.

In accordance to another embodiment of the present invention, the advantages of the embodiments shown in FIGS. **1–19**, i.e., having a rigid central portion **36**, **136**, **236**, **336** or **446** and relatively flexible intermediate portion **38**, **138**, **238**, **338** or **448**, so that upon impact the intermediate portion deforms to provide high initial velocity while the central portion is substantially un-deformed so that the ball flies on-target ($FS_c/FS_I \geqq 3$), among others, can be combined with the advantages of the embodiments shown in FIGS. **20–23**, i.e., vertical and lateral control of the ball's flight. As illustrated in FIGS. **24–25**, golf club head **610** comprises hitting face **616**, which has a central portion **36**, **136**, **236**, **336** or **436** surrounded by an intermediate portion comprising crown intermediate portion **620** and sole intermediate portion **622**. Face **616** may also comprise an optional perimeter region (not shown). Preferably, the ratio of flexural stiffness between the central region and any portion of the intermediate region is greater than or equal to about 3.0, and more preferably between about 6.0 and about 12.0. In other words, this ratio between the central region and the crown intermediate portion **620** and between the central region and the sole intermediate portion **622** is greater than or equal to about 3.0, and more preferably between about 6.0 and about 12.0.

In this embodiment, preferably the flexural stiffness of the two intermediate portions **620** and **622** are different. Crown intermediate portion **620** may have a lower flexural stiffness than sole intermediate portion **622**, or vice versa, depending on the desired launch angle of the ball. In one non-limiting example, the ratio of flexural stiffness between the central region and the crown intermediate portion **620** is about 9.0, while the same ratio between the central region and the sole intermediate portion is about 6.0 to control the launch angle of the golf ball.

On the other hand, to control the lateral launch angle of the golf ball while maintaining the high initial velocity produced by the ($FS_c/FS_I \geqq 3$) flexural stiffness ratio, hitting face **616** may comprise central region **36**, **136**, **236**, **336** or **436** and an intermediate region comprising heel intermediate portion **624** and toe intermediate portion **626**, as shown in FIG. **26**. Preferably, the ratio of flexural stiffness between the central region and any portion of the intermediate region is greater than or equal to about 3.0, and more preferably between about 6.0 and about 12.0. In other words, this ratio between the central region and the heel intermediate portion **620** and between the central region and the toe intermediate portion **622** is greater than or equal to about 3.0, and more preferably between about 6.0 and about 12.0, or greater than 12.0.

In this embodiment, preferably the flexural stiffness of the two intermediate portions **624** and **626** are different. Heel intermediate portion **620** may have a lower flexural stiffness than toe intermediate portion **622**, or vice versa, depending on the desired lateral angle of the ball. In one non-limiting example, the ratio of flexural stiffness between the central region and the heel intermediate portion **620** is about 9.0, while the same ratio between the central region and the toe intermediate portion is about 6.0 to control the lateral angle of the golf ball.

In accordance to another aspect of the invention, hitting face **616** may comprise a central region, as discussed above, and an intermediate region comprising four portions: crown-heel intermediate portion, crown-toe intermediate portion, sole-toe intermediate portion and sole-heel intermediate portion, similar to the embodiment shown in FIG. **22**. Each intermediate portion preferably has different flexural stiffness to vary the launch and lateral angle of the golf ball.

Furthermore, the ratio of flexural stiffness between the central region and each of the intermediate portions is greater than or equal to about 3.0, and more preferably between about 6.0 and about 12.0.

While various descriptions of the present invention are described above, it should be understood that the various features of each embodiment can be used alone or in any combination thereof. Therefore, this invention is not to be limited to only the specifically preferred embodiments depicted herein. Further, it should be understood that variations and modifications within the spirit and scope of the invention may occur to those skilled in the art to which the invention pertains. For example, the face and/or individual portions can have thickness variations in a step-wise or continuous fashion. Other modifications include a perimeter portion that has a thickness that is greater than or less than the adjacent, intermediate portion. In addition, the shapes of the central, intermediate, and perimeter portions are not limited to those disclosed herein. Accordingly, all expedient modifications readily attainable by one versed in the art from the disclosure set forth herein that are within the scope and spirit of the present invention are to be included as further embodiments of the present invention. The scope of the present invention is accordingly defined as set forth in the appended claims.

What is claimed is:

1. A golf club head adapted for attachment to a shaft and having a hitting face, wherein the hitting face comprises a directional control portion, said directional control portion comprises two or more non-concentric zones having different flexural stiffness with at least a varying crown to sole flexural stiffness, such that when the hitting face impacts a golf ball the zones exhibit different degrees of deformation to selectively control the direction of the flight of the golf ball, wherein the flexural stiffness is asymmetric about at least one axis on the hitting face, and the coefficient of restitution of the club head is greater than about 0.81.

2. The golf club head of claim 1, further comprising a perimeter portion disposed around the directional control portion, wherein the flexural stiffness of the perimeter portion is at least about two times greater than the flexural stiffness of the directional control portion.

3. The golf club head of claim 1, wherein the flexural stiffness of a first zone of said two or more zones is between about 8,500 lb·in to about 60,000 lb·in.

4. The golf club bead of claim 3, wherein the flexural stiffness of a second zone of said two or more zones is about 0.5 time to about two times the flexural stiffness of the first zone.

5. The golf club head of claim 3, wherein the flexural stiffness of a third zone of said two or more zones is about 0.7 times to about 1.3 times the flexural stiffness of the first zone.

6. The golf club head of claim 3, wherein the flexural stiffness of a fourth zone of said two or more zones is about 0.7 times to about two times the flexural stiffness of the first zone.

7. The golf club head of claim 1, wherein the directional control portion comprises an upper toe zone and a lower heel zone.

8. The golf club head of claim 1, wherein the directional control portion comprises a lateral heel zone and a lateral toe zone.

9. The golf club head of claim 1, wherein the directional control portion comprises four zones, and wherein the zones are delineated by a vertical center line and a horizontal center line of the hitting face.

10. The golf club head of claim 1, wherein the hitting face comprises a laminate material.

* * * * *

EXHIBIT C

US007140975B2

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Bissonnette et al.

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(45) **Date of Patent: *Nov. 28, 2006**

(54) **GOLD CLUB HEAD WITH VARIABLE FLEXURAL STIFFNESS FOR CONTROLLED BALL FLIGHT AND TRAJECTORY**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 14 days.

This patent is subject to a terminal disclaimer.

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A63B 53/04 (2006.01)

(52) **U.S. Cl.** 473/329; 473/345; 473/349

(58) **Field of Classification Search** 473/324–350, 473/290–291

See application file for complete search history.

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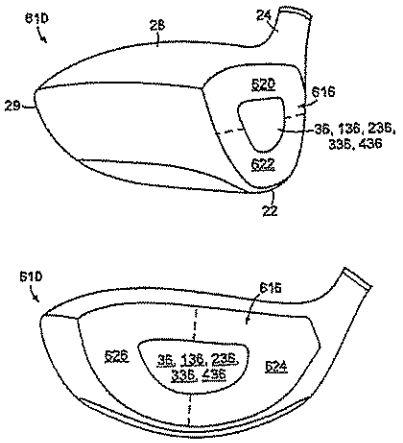
(57) **ABSTRACT**

The present invention relates to a golf club head with a hitting face. The hitting face comprises a directional control portion, which has at least two zones with different flexural stiffness, such that when the hitting face strikes a golf ball the two zones deform differently to selectively control the direction of the flight of the golf ball. The directional control portion may comprise an upper zone and a lower zone, where the upper zone has a lower flexural stiffness. Alternatively, the lower zone has a lower flexural stiffness. On the other hand, the directional control portion may comprise a left zone and a right zone, and either the left or right zone may have a lower flexural stiffness to selectively control the lateral launch angle either to the left of right. The hitting face may further comprise a central zone disposed within the directional control zone, wherein the central zone has a flexural stiffness of at least about three times greater than the flexural stiffness of the directional control zone.

12 Claims, 13 Drawing Sheets



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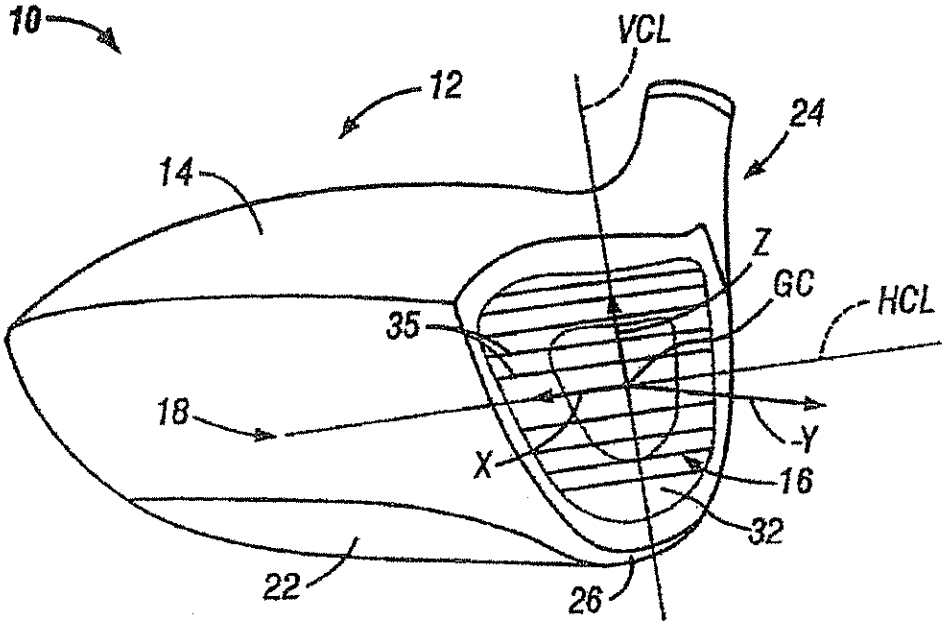

FIG .1

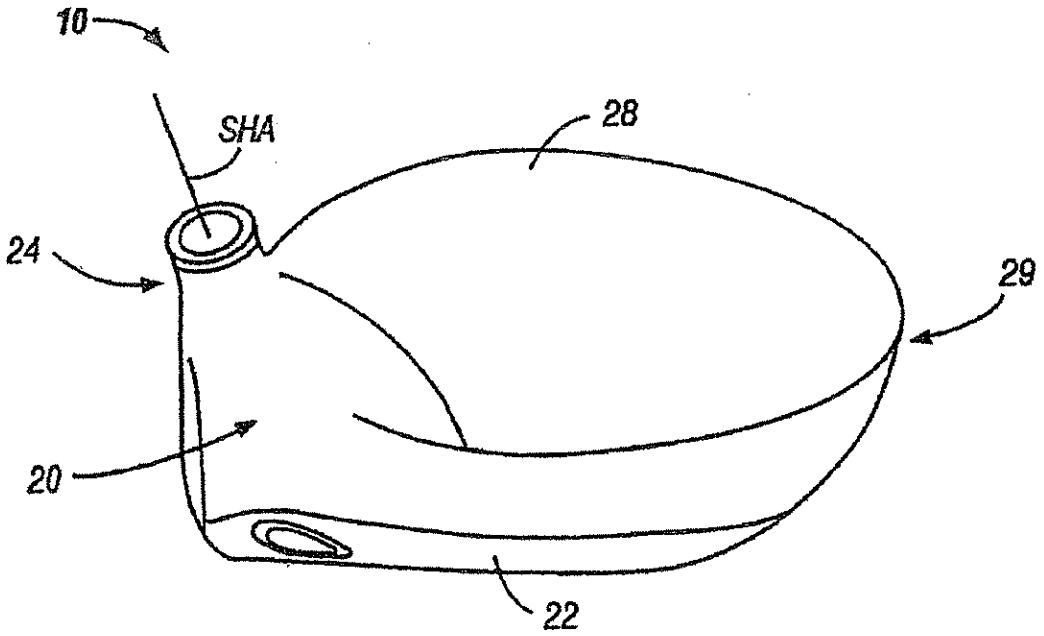

FIG. 2

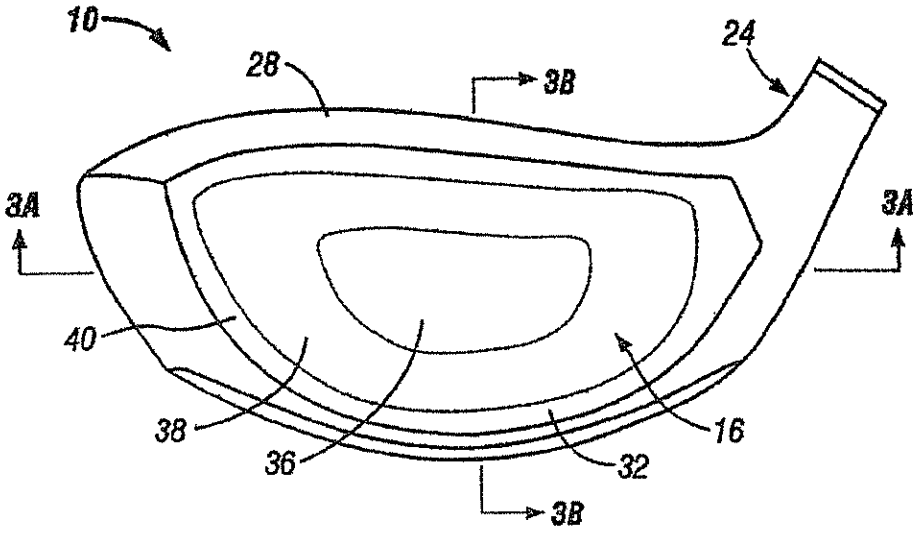

FIG. 3

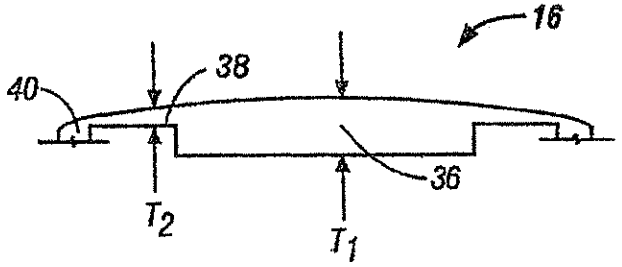

FIG 3A

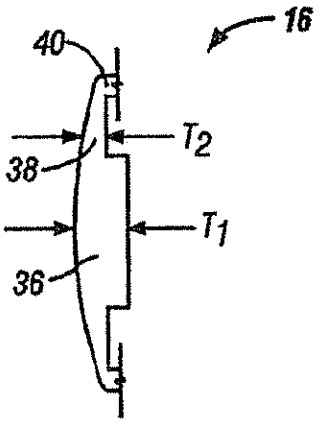

FIG. 3B

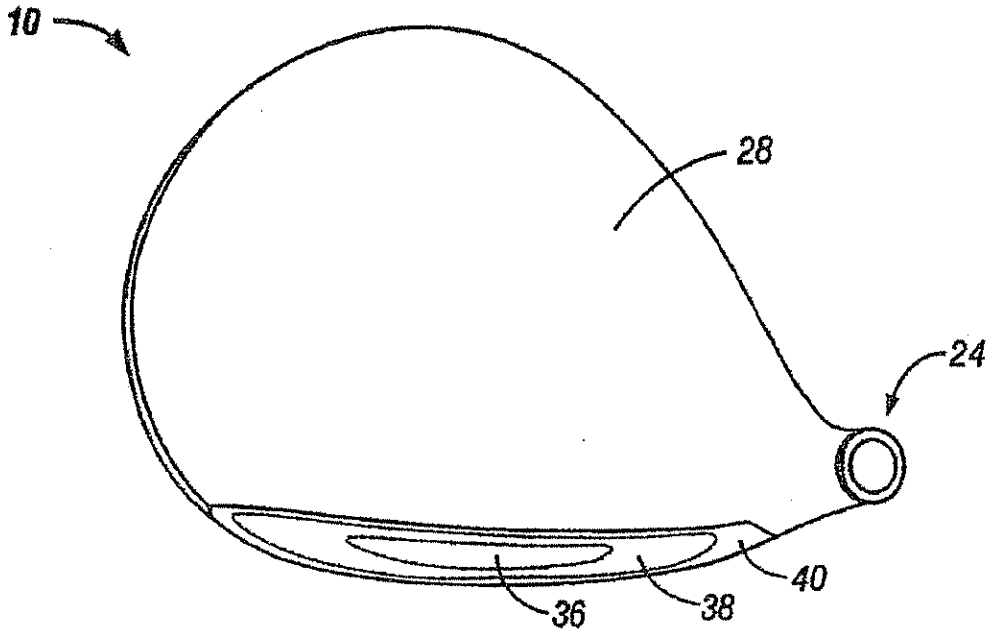

FIG. 4

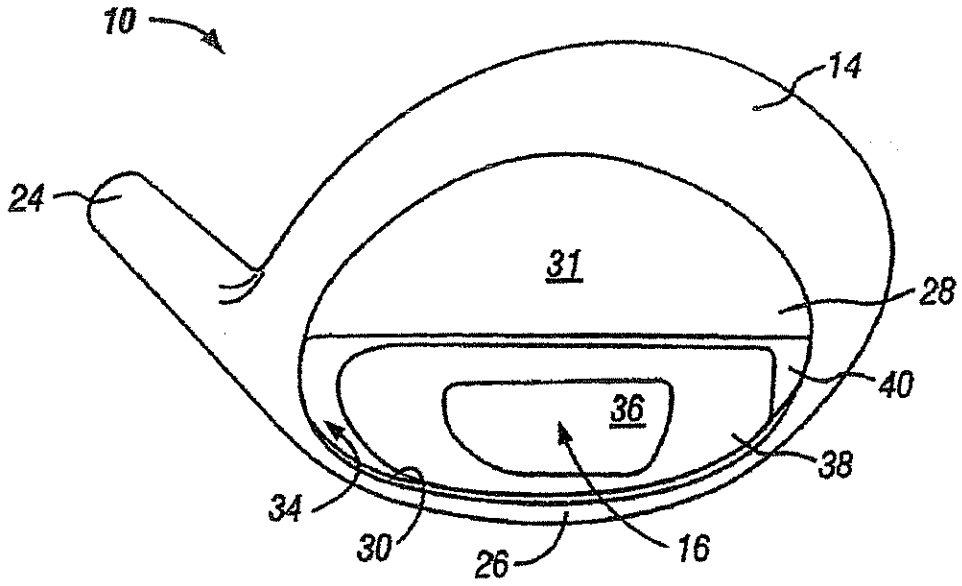

FIG. 5

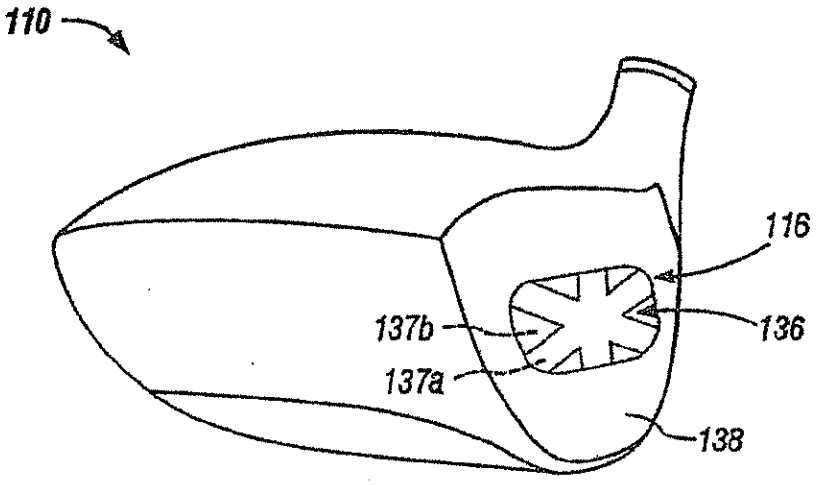

FIG. 6

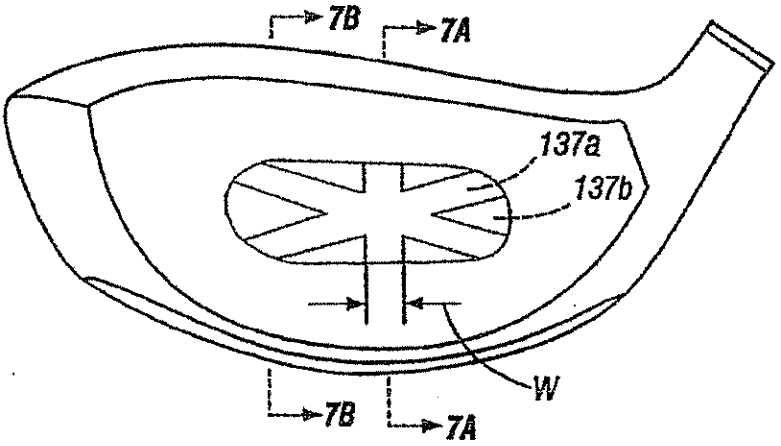

FIG. 7

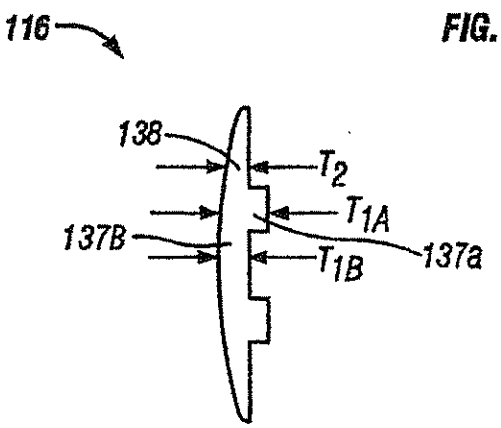

FIG. 7A

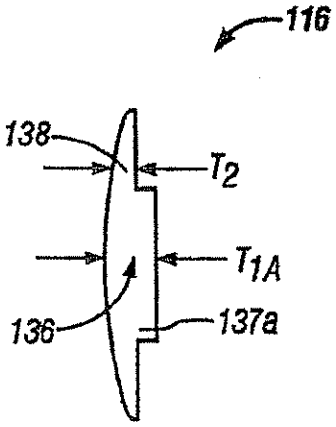

FIG. 7B

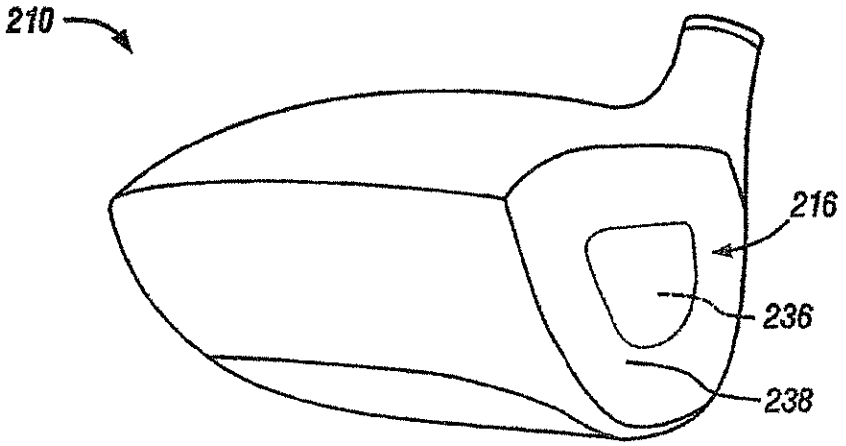

FIG. 8

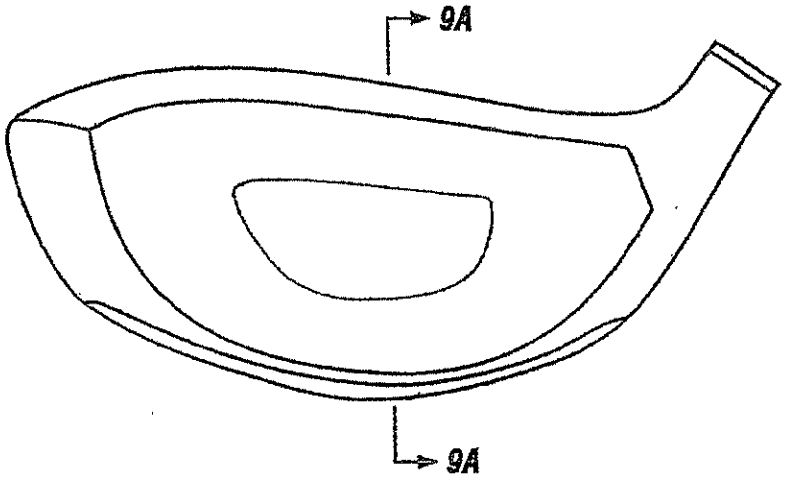

FIG. 9

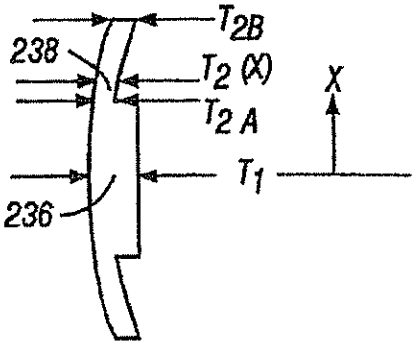

FIG. 9A

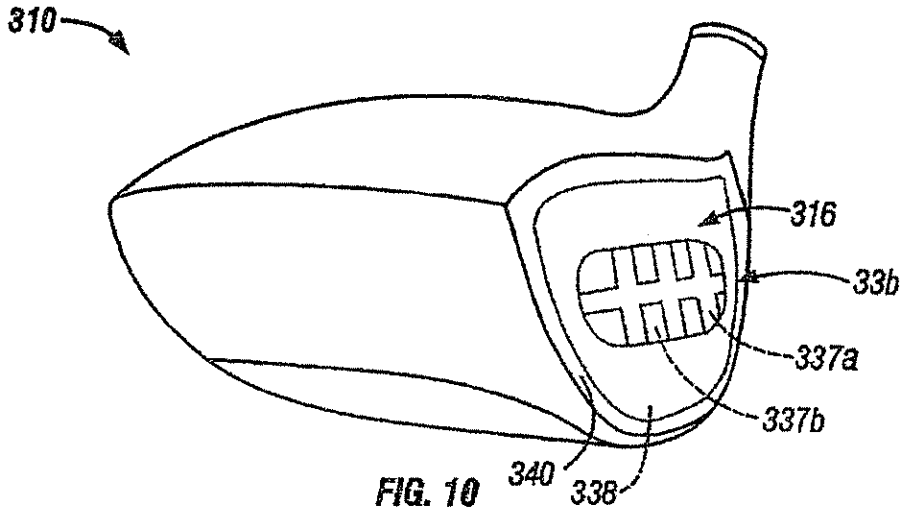

FIG. 10

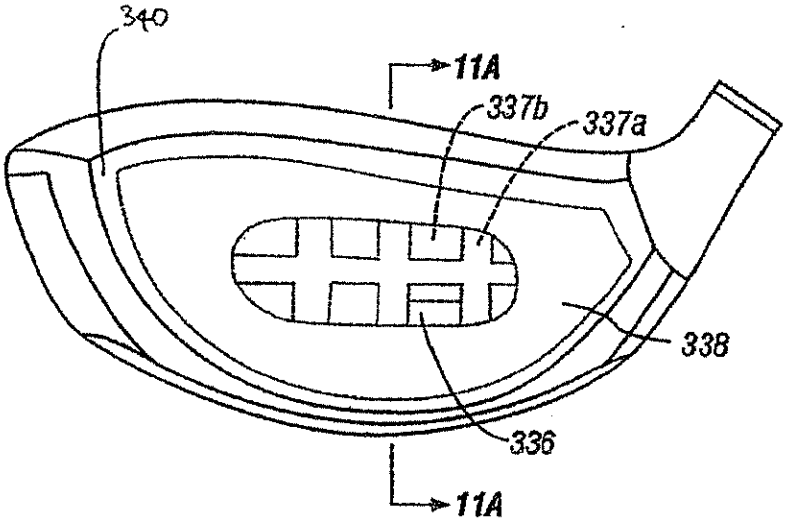

FIG. 11

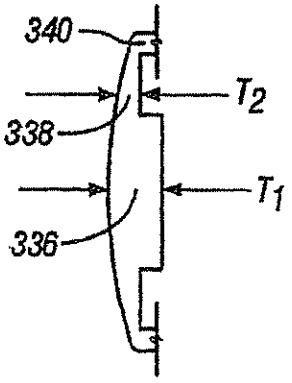

FIG. 11A

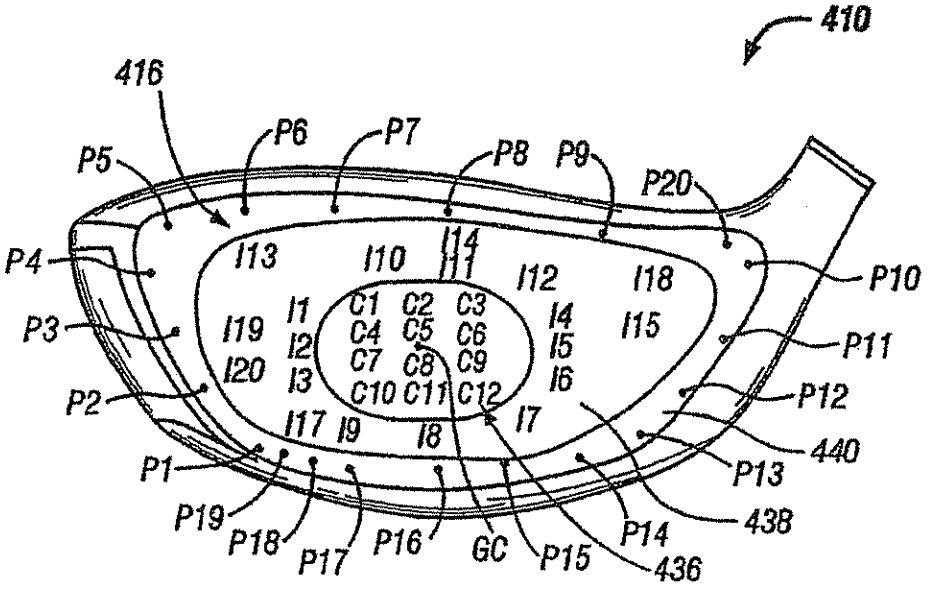
410
416
P5
P6
P7
P8
P9
P20
P4
P10
P3
P11
P2
P12
P1
P13
440
438
P19
P18
P17
P16
GC
P15
P14
436
I13
I10
I14
I11
I12
I18
I19
I1
C1
C2
C3
I4
I15
I2
C4
C5
C6
I5
I20
I3
C7
C8
C9
I6
C10
C11
C12
I17
I9
I8
I7

FIG. 12

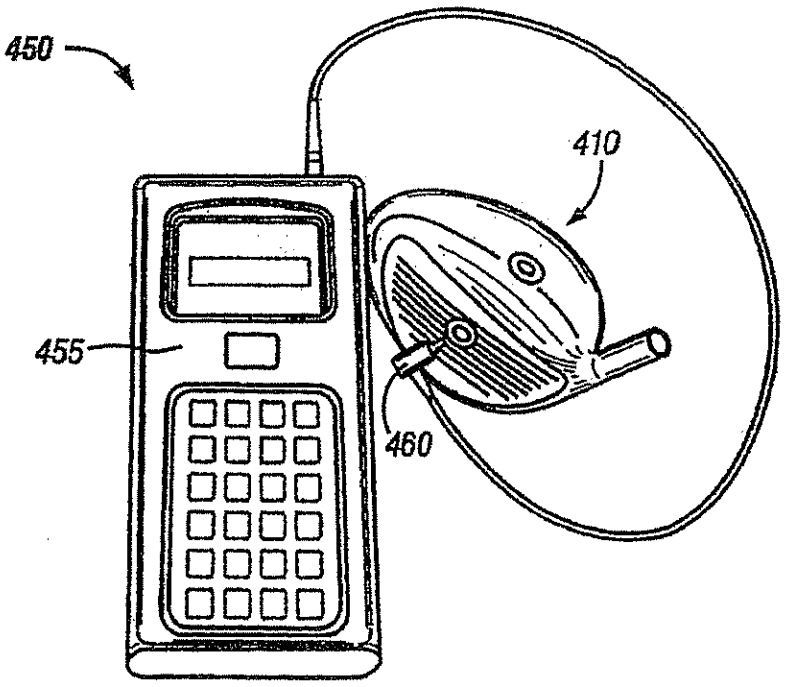
450
410
455
460

FIG. 13

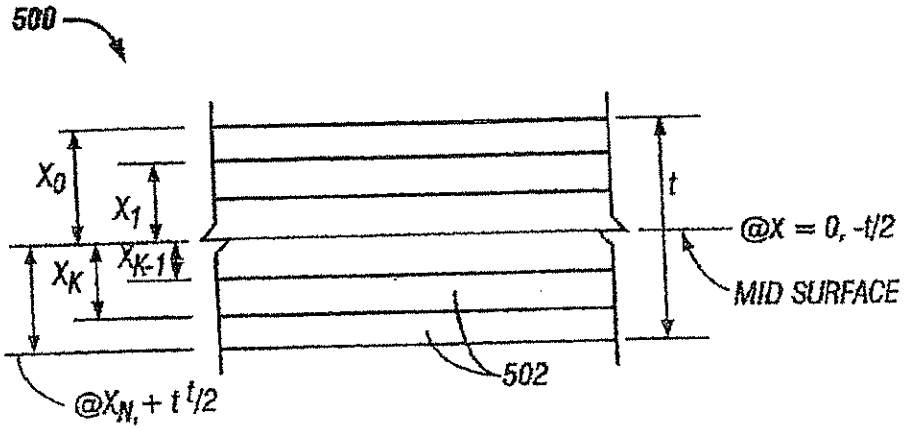

FIG. 14

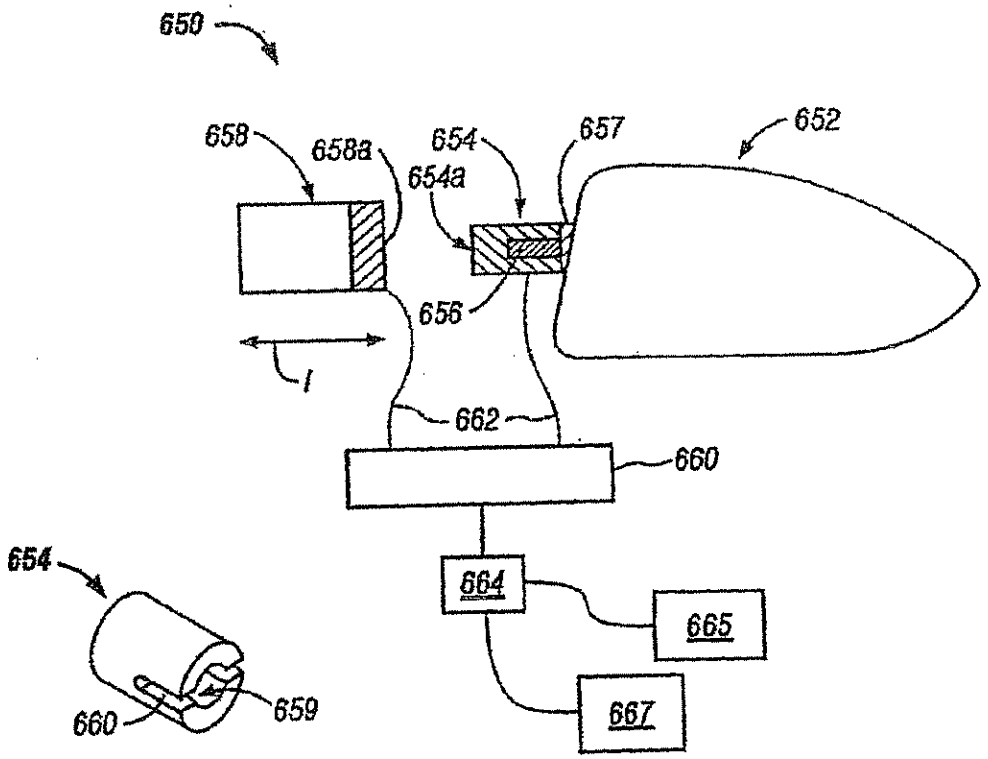

FIG. 15B

FIG. 15A

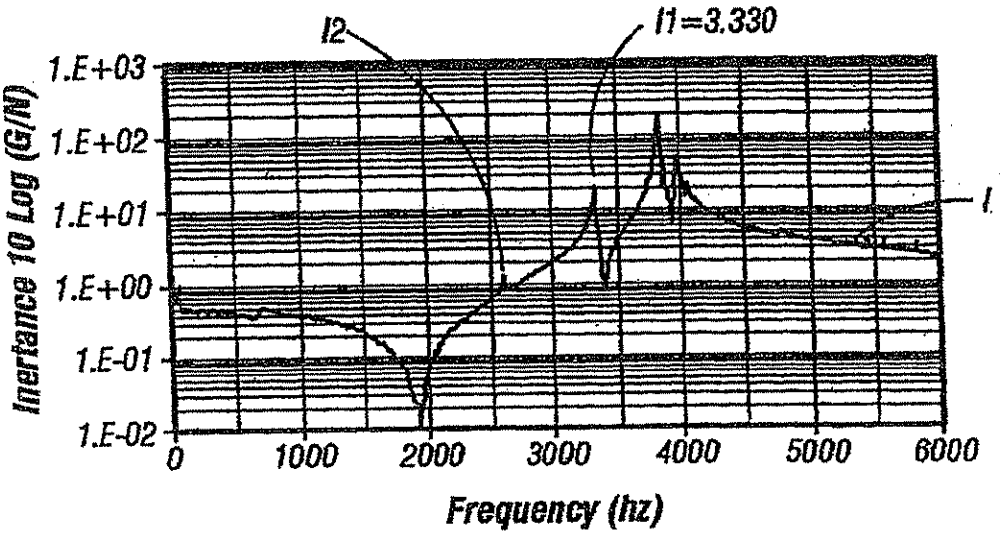
I2
I1=3.330
I
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
Inertance 10 Log (G/N)
0
1000
2000
3000
4000
5000
6000
Frequency (hz)

FIG. 16

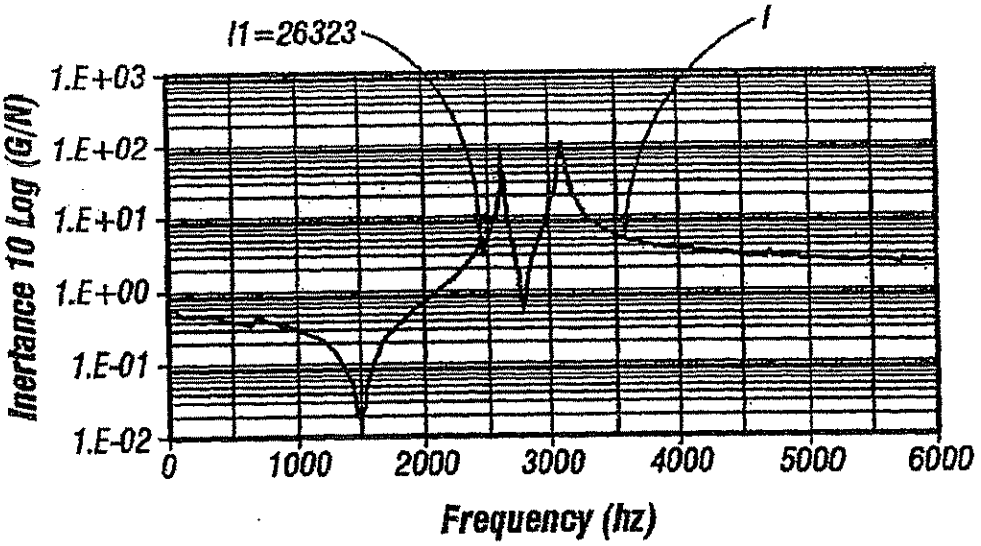
I1=26323
I
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
Inertance 10 Log (G/N)
0
1000
2000
3000
4000
5000
6000
Frequency (hz)

FIG. 17

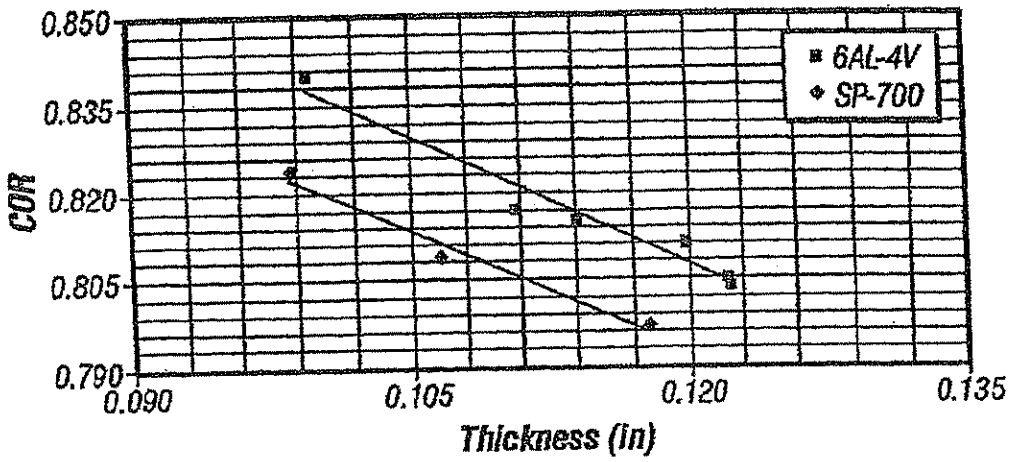
0.850
0.835
0.820
0.805
0.790
COR
0.090
0.105
0.120
0.135
Thickness (in)
6AL-4V
SP-700

FIG. 18

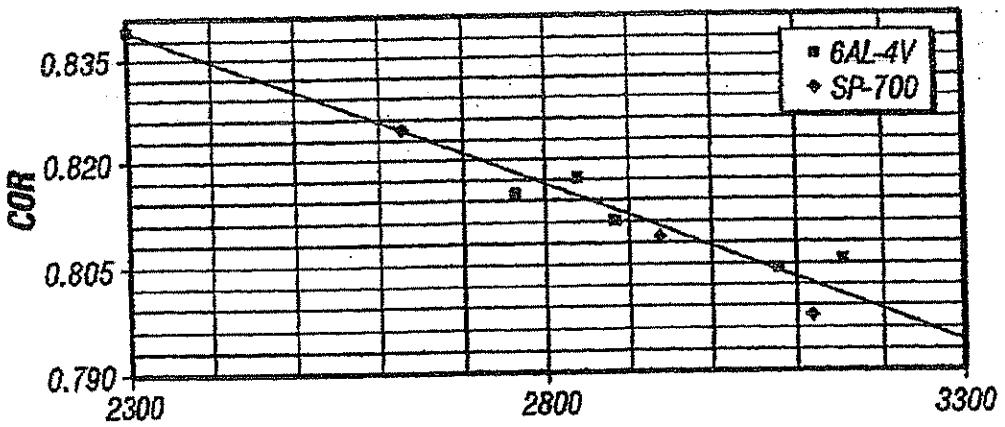
0.835
0.820
0.805
0.790
COR
2300
2800
3300
Frequency (hz)
6AL-4V
SP-700

FIG. 19

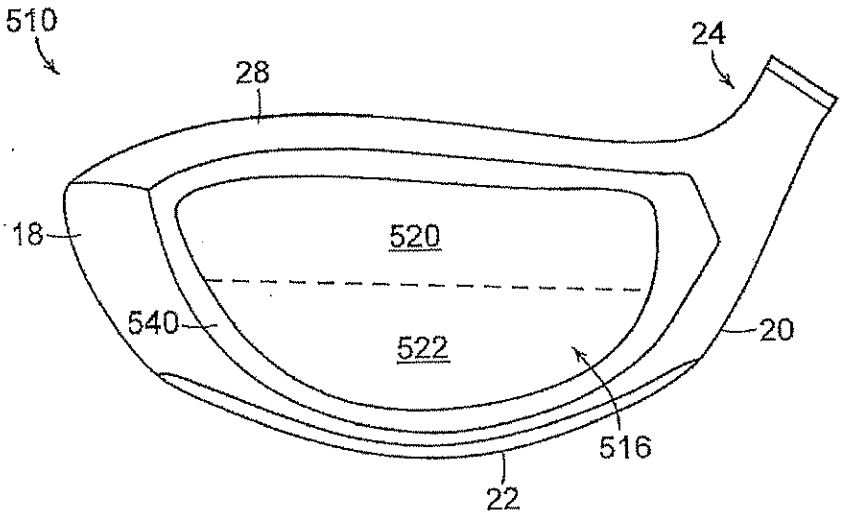
510
28
24
18
520
540
522
20
516
22

FIG. 20

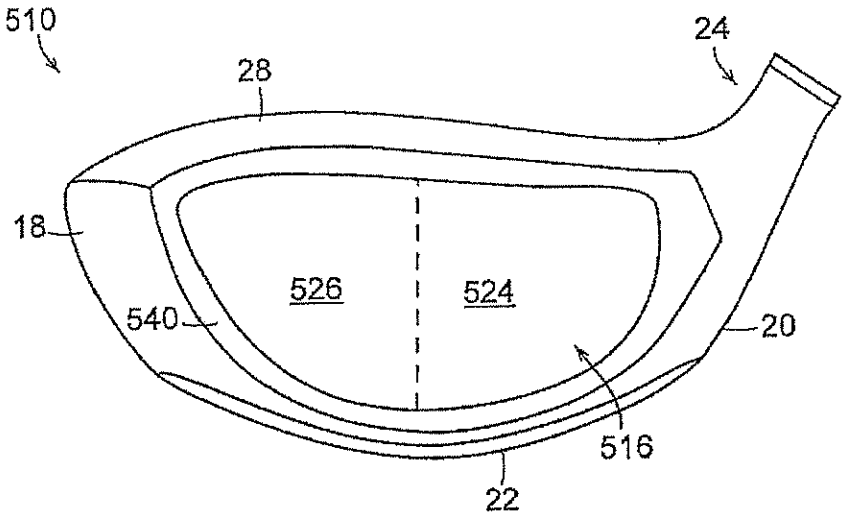
510
28
24
18
526
524
540
20
516
22

FIG. 21

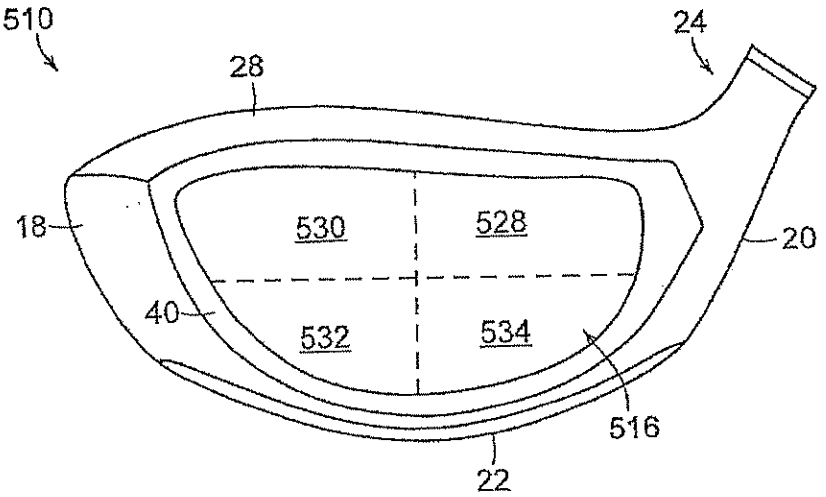

FIG. 22

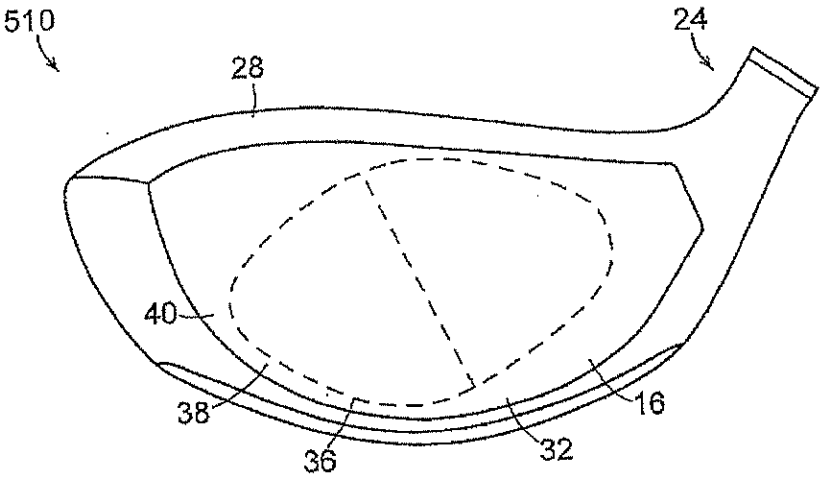

FIG. 23

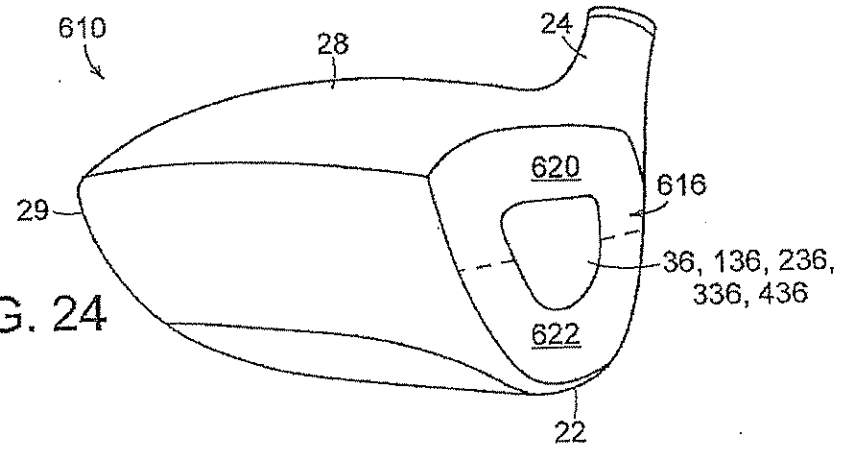

FIG. 24

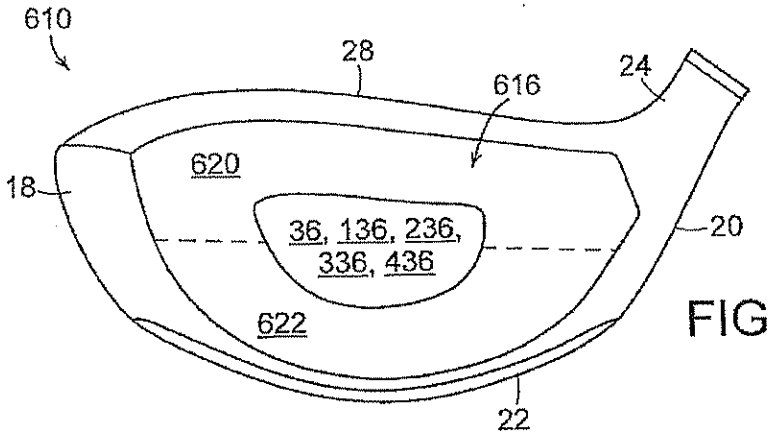

FIG. 25

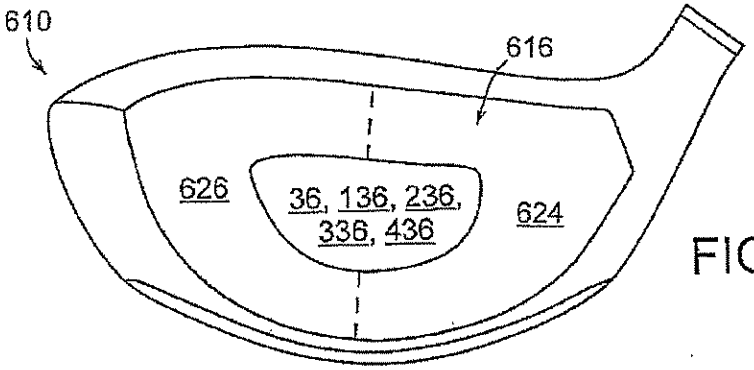

FIG. 26

GOLD CLUB HEAD WITH VARIABLE FLEXURAL STIFFNESS FOR CONTROLLED BALL FLIGHT AND TRAJECTORY

CROSS-REFERENCE TO RELATED APPLICATION

This non-provisional utility application is a divisional application of co-pending U.S. patent application Ser. No. 10/428,051 filed on May 1, 2003, which is a continuation-in-part of U.S. patent application Ser. No. 09/551,771 filed on Apr. 18, 2000, now U.S. Pat. No. 6,605,007. The disclosure of the parent patent application and patent are incorporated herein in their entirety.

FIELD OF THE INVENTION

The invention is an improved golf club head. More particularly, the invention is a golf club head with an improved striking face having discrete zones with varying flexural stiffness, improved accuracy, and a high coefficient of restitution.

BACKGROUND OF THE INVENTION

The complexities of golf club design are well-known. The specifications for each component of the club (i.e., the club head, shaft, hosel, grip, and subcomponents thereof) directly impact the performance of the club. Thus, by varying the design specifications, a golf club can be tailored to have specific performance characteristics.

The design of club heads has long been studied. Among the more prominent considerations in club head design are loft, lie, face angle, horizontal face bulge, vertical face roll, face progression, face size, sole curvature, center of gravity, material selection, and overall head weight. While this basic set of criteria is generally the focus of golf club engineering, several other design aspects must also be addressed. The interior design of the club head may be tailored to achieve particular characteristics, such as the inclusion of hosel or shaft attachment means, perimeter weights on the face or body of the club head, and fillers within hollow club heads to improve acoustics.

Golf club heads must also be strong to withstand the repeated impacts that occur during collisions between the golf club and the ball. The loading that occurs during this transient event can accelerate the golf ball to about four orders of magnitude greater than gravity. Thus, the club face and body should be designed to resist permanent deformation or catastrophic failure by material yield or fracture. Conventional hollow metal wood drivers made from titanium typically have a uniform face thickness exceeding 0.010 inch to ensure structural integrity of the club head.

Players generally seek a metal wood driver and golf ball combination that delivers maximum distance and landing accuracy. The distance a ball travels after impact is dictated by the magnitude and direction of the ball's translational velocity and the ball's rotational velocity or spin. Environmental conditions, including atmospheric pressure, humidity, temperature, and wind speed further influence the ball's flight. However, these environmental effects are beyond the control of the golf equipment manufacturer. Golf ball landing accuracy is driven by a number of factors as well. Some of these factors are attributed to club head design, such as center of gravity, face curvature and club face flexibility.

The United States Golf Association (USGA), the governing body for the rules of golf in the United States, has

specifications for the performance of golf balls. These performance specifications dictate the size and weight of a conforming golf ball. One USGA rule limits the golf ball's initial velocity after a prescribed impact to 250 feet per second±2% (or 255 feet per second maximum initial velocity). To achieve greater golf ball travel distance, ball velocity after impact must be maximized while remaining within this rule.

Generally, golf ball travel distance is a function of the total kinetic energy imparted to the ball during impact with the club head, along with associated environmental effects. During impact, kinetic energy is transferred from the club and stored as elastic strain energy in the club head and as viscoelastic strain energy in the ball. After impact, the stored energy in the ball and in the club is transformed back into kinetic energy in the form of translational and rotational velocity of the ball as well as the club. Since the collision is not perfectly elastic, a portion of energy is dissipated in club head vibration and in viscoelastic relaxation of the ball. Viscoelastic relaxation is a material property of the polymeric materials used in all manufactured golf balls.

Viscoelastic relaxation of the ball is a parasitic energy source, which is dependent upon the rate of deformation. To minimize this effect, the rate of deformation must be reduced. This may be accomplished by allowing more club face deformation during impact. Since metallic deformation may be purely elastic, the strain energy stored in the club face is returned to the ball after impact thereby increasing the ball's outbound velocity after impact.

A variety of techniques may be utilized to vary the allowable deformation of the club face, including uniform face thinning, thinned faces with ribbed stiffeners and varying thickness, among others. These designs should have sufficient structural integrity to withstand repeated impacts without permanent deformation of the club face. In general, conventional club heads also exhibit wide variations in the coefficient of restitution (COR) depending on the impact location on the face of the club. Furthermore, the accuracy of conventional clubs is highly dependent on impact location.

Thus, there is a need for a golf club head with a hitting face that maximizes golf ball travel distance while maintaining golf ball landing accuracy.

SUMMARY OF THE INVENTION

The present invention relates to a golf club head adapted for attachment to a shaft. The head includes a face and a body. The face is configured and dimensioned so that it includes a central portion and an adjacent surrounding intermediate portion. The central portion is relatively rigid and the intermediate portion is relatively flexible so that upon ball impact, the intermediate portion of the face deforms to provide high ball velocity, while the central portion is substantially un-deformed so that the ball flies on-target. Thus, upon ball impact the deformation of the intermediate portion allows the central region to move into and out of the club head as a unit. As a result, the head exhibits a coefficient of restitution greater than 0.81.

The above is accomplished by providing the central portion with a first flexural stiffness and the intermediate portion with a second flexural stiffness. Flexural stiffness is defined as Young's modulus or elastic modulus (E) times the portion's thickness (t) cubed or Et^3. The first flexural stiffness is substantially different from the second flexural stiffness. As a result, upon ball impact, the intermediate portion exhibits substantial deformation so that the central

portion moves into the club head, and the central portion exhibits minimal deformation.

In one embodiment, the first flexural stiffness is at least three times the second flexural stiffness. In other embodiments, the first flexural stiffness is six to twelve times the second flexural stiffness. More preferably, the first flexural stiffness is greater than 25,000 lb-in. Most preferably, the first flexural stiffness is greater than 55,000 lb-in. Preferably, the second flexural stiffness is less than 16,000 lb-in. More preferably, the second flexural stiffness is less than 10,000 lb-in.

Since the flexural stiffness is a function of material and thickness, the following techniques can be used to achieve the substantial difference between the first and second flexural stiffness: 1) different materials can be used for each portion, 2) different thicknesses can be used for each portion, or 3) different materials and thicknesses can be used for each portion. For example, in one embodiment, the thickness of the central portion is greater than the thickness of the intermediate portion and the material for both portions is the same, e.g., titanium or steel.

The golf club head further includes a perimeter portion disposed between the intermediate portion and the body of the club. In one embodiment, the perimeter portion has a third flexural stiffness that is at least two times greater than the second flexural stiffness. The area of the perimeter portion preferably comprises less than 30% of the total area of the club head face.

In an alternative embodiment, a golf club head includes a shell that defines an inner cavity and a face. The face defines a face area and includes a first portion in the center and a second portion adjacent thereto. The first portion has a first thickness and defines a first area. The second portion has a second thickness. The first area is between about 15% and about 60% of the total face area, and the first thickness is greater than the second thickness. More preferably, the first area is between about 20% and 50% of the face area. The shell further includes a top crown portion and a spaced-apart sole plate, a heel portion and a spaced toe portion, and a rear spaced from the face.

In the club heads discussed above, the first, second, and third portions can have various shapes, such as the shape of the face or an elliptical shape. Furthermore, the club head inner cavities can have a volume greater than about 250 cubic centimeters, and more preferably a volume greater than about 275 cubic centimeters. It is preferred that the face of the club head has a loft of less than about 13°.

In addition, the central, intermediate, and perimeter portions can each have variable thicknesses.

Another feature of the present invention is locating the center of gravity of the club head with respect to a Cartesian coordinate system. The origin of the Cartesian coordinate system preferably coincides with the geometric center of the hitting face. The X-axis is a horizontal axis positioned tangent to the geometric center of the hitting face with the positive direction toward the heel of the club. The Y-axis is another horizontal axis orthogonal to the X-axis with the positive direction toward the rear of the club. The Z-axis is a vertical axis orthogonal to both the X-axis and Y-axis with the positive direction toward the crown of the club. The center of gravity is preferably located behind and lower than the geometric center of the face.

In one embodiment, the center of gravity is spaced from the geometric center along the Z-axis by a first distance of at least about 0.1". More preferably, the center of gravity is spaced from the geometric center along the Z-axis toward the sole plate, wherein the first distance is at least about 0.15". In another embodiment, the center of gravity is spaced a second distance from the geometric center along the X-axis, wherein the second distance is less than about 0.02". In addition, the center of gravity is spaced a third distance from the geometric center along the Y-axis toward the rear portion, wherein the third distance is less than about 1.25".

The present invention is also directed to a golf club head having a hitting face and adapted for attachment to a shaft. The face includes a total face area and first primary resonant frequency, which is preferably less than about 2900 Hz. The face further includes a central zone that includes a geometric center of the face, and an intermediate zone disposed adjacent the central zone. The central zone has a first flexural stiffness and a central zone area that is at least 15% of the total face area. The intermediate zone has a second flexural stiffness. The first flexural stiffness is at least 25,000 lb-in and greater than the second flexural stiffness.

An embodiment of the present invention is directed to a golf club head adapted for attachment to a shaft and having a hitting face, wherein the hitting face comprises a directional control portion, said directional controlled portion comprises two or more zones having different flexural stiffness, such that when the hitting face impacts a golf ball the zones exhibit different degrees of deformation to selectively control the direction of the flight of the golf ball. The hitting face may further include a central portion disposed within the directional control portion, which contains a geometric center of the hitting face, and the flexural stiffness of the central portion is at least about three times, preferably at least about six times and more preferably at least about twelve times, greater than the flexural stiffness of the directional control portion.

The golf club head may further have a perimeter portion disposed around the directional control portion, wherein the flexural stiffness of the perimeter portion is at least about two times greater than the flexural stiffness of the directional control portion. In accordance to one aspect, the flexural stiffness of a first zone of said two or more directional control zones is between about 8,500 lb-in to about 60,000 lb-in. The flexural stiffness of a second zone of said two or more zones is about 0.5 time to about two times the flexural stiffness of the first zone. Furthermore, the flexural stiffness of a third zone of said two or more zones is about 0.7 times to about 1.3 times the flexural stiffness of the first zone, and the flexural stiffness of a fourth zone of said two or more zones is about 0.7 times to about two times the flexural stiffness of the first zone.

The directional control portion may comprise an upper crown zone and a lower heel zone, or may comprise a lateral heel zone and a lateral toe zone. Alternatively, the directional control portion may comprise all four of these zones. Preferably, these four zones are delineated by a vertical center line and a horizontal center line of the hitting face.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred features of the present invention are disclosed in the accompanying drawings, wherein similar reference characters denote similar elements throughout the several views, and wherein:

FIG. 1 is a toe side, front, and perspective view of a first embodiment of a golf club head of the present invention;

FIG. 2 is a heel side, rear, and perspective view of the golf club head of FIG. 1;

FIG. 3 is a front, elevational view of the golf club head of FIG. 1;

FIG. 3A is a cross-sectional view of the face of the golf club head of FIG. 3 along line 3A—3A;

FIG. 3B shows a cross-sectional view the face of the golf club head of FIG. 3 along line 3B—3B;

FIG. 4 is a top view of the golf club head of FIG. 1;

FIG. 5 is a bottom, perspective view of the golf club head of FIG. 1;

FIG. 6 is a toe side, front, and perspective view of a second embodiment of a golf club head of the present invention;

FIG. 7 is a front, elevational view of the golf club head of FIG. 6;

FIG. 7A is a cross-sectional view of the face of the golf club head of FIG. 7 along line 7A—7A;

FIG. 7B shows a cross-sectional view the face of the golf club head of FIG. 7 along line 7B—7B;

FIG. 8 is a toe side, front, and perspective view of a third embodiment of a golf club head of the present invention;

FIG. 9 is a front, elevational view of the golf club head of FIG. 8;

FIG. 9A is a cross-sectional view of the face of the golf club head of FIG. 9 along line 9A—9A;

FIG. 10 is a toe side, front, and perspective view of a fourth embodiment of a golf club head of the present invention;

FIG. 11 is a front, elevational view of the golf club head of FIG. 10;

FIG. 11A is a cross-sectional view of the face of the golf club head of FIG. 11 along line 11A—11A;

FIG. 12 is an enlarged, front view of a golf club head with ultrasonic thickness measurement locations indicated;

FIG. 13 is a schematic representation of the apparatus for taking an ultrasonic thickness measurement on the face of a club head;

FIG. 14 is an enlarged, elevational view of a portion of the face of a laminated golf club head of the present invention;

FIG. 15 is a schematic representation of a testing apparatus for obtaining frequency response data from a club head;

FIG. 15A is a perspective view of an attached mass for use with the testing apparatus of FIG. 15;

FIG. 16 is a graph of inertance versus frequency for a conventional club head;

FIG. 17 is a graph of inertance versus frequency for the inventive club head;

FIG. 18 is a graph of COR versus face thickness for two alternative titanium alloys;

FIG. 19 is a graph of COR versus first resonant frequency for two alternative titanium alloys;

FIGS. 20–23 are front, elevational views of another embodiment in accordance to the present invention; and

FIGS. 24–26 are perspective and front, elevational views of another embodiment in accordance to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIGS. 1–5, a first embodiment of a golf club head 10 of the present invention is shown. Club head 10 includes shell 12 with body 14, hitting face 16, toe portion 18, heel portion 20, sole plate 22, hosel 24, bottom portion 26, crown portion 28, and rear portion 29. The sole plate 22 fits in a recess 30 (as shown in FIG. 5) in the bottom portion 26 of body 14. The shell 12 and sole plate 22 create an inner cavity 31 (as shown in FIG. 5). The hitting face 16 has an exterior surface 32 and an interior surface 34. The exterior surface 32 may optionally have grooves 35.

A golf club shaft (not shown) is attached at hosel 24 and is disposed along a shaft axis SHA. The hosel may extend to the bottom of the club head, may terminate at a location between the top and bottom portions of the head, or the hosel can terminate flush with the top portion and extend into the cavity in the head.

Inner cavity 31 of club head 10 may be empty, or alternatively may be filled with foam or other low specific gravity material. It is preferred that the inner cavity 31 has a volume greater than 250 cubic centimeters, and more preferably greater than 275 cubic centimeters. Preferably, the mass of the inventive club head is greater than 150 grams but less than 220 grams.

Referring to FIGS. 3–3B, the face 16 includes a central zone or portion 36, an intermediate zone or surrounding portion 38 adjacent the central zone 36, and an optional perimeter zone or outer portion 40. The intermediate zone 38 preferably surrounds central zone 36, and the perimeter zone 40 preferably surrounds the intermediate zone 38. The perimeter zone 40 is located between the intermediate zone 38 and crown portion 28. In the following specification and claims, the central zone 36 is a contiguous zone centrally located on the hitting face 16 and containing a geometric center ("GC") of the hitting face.

Zones 36, 38 and 40 have a shape that is similar to the shape of hitting face 16 only with a smaller area, as discussed in detail below. Preferably, zones 36, 38 and 40 are substantially concentric to each other within hitting face 16. The central zone 36 has a first thickness t_1. The intermediate zone 38 has a second thickness t_2. The first thickness t_1 is greater than the second thickness t_2. Typically, when the club head is cast, the perimeter zone 40 will be thicker than the intermediate zone 38. However, the present invention is not limited to this configuration. Preferably, the first thickness t_1 is equal to about one and a half (1.5) times the thickness t_2 to about four (4) times the thickness t_2 of the intermediate zone 38.

The thickness relationships between the zones 36, 38, and 40 are provided so that a predetermined relationship exists between flexural stiffness exhibited by each of the zones. Flexural stiffness (FS) of each zone is defined by the following simplified formula:

$$FS=Et^3$$

where,

E=the elastic modulus or Young's modulus of the material of the zone; and

t=the thickness of the zone.

The central zone 36 has a first flexural stiffness FS_1. The intermediate zone 38 has a second flexural stiffness FS_2. The perimeter zone 40 has a third flexural stiffness FS_3. The predetermined relationship between the portions is that the first flexural stiffness FS_1 is substantially greater than the second flexural stiffness FS_2, and optionally the third flexural stiffness FS_3 is substantially greater than the second flexural stiffness FS_2. Preferably, the first flexural stiffness FS_1 is at least three times greater than the second flexural stiffness FS_2. As a ratio the following relationship must be satisfied:

$$(FS_1/FS_2)\geq 3.$$

This expression means that the ratio of the central zone flexural stiffness FS_1 to the intermediate zone flexural stiffness FS_2 is equal to or greater than 3.0. When the above ratio

of flexural stiffness is less than three, the central zone sustains excessive deformation during impact and accuracy of the club is diminished. More preferably, the first flexural stiffness FS_1 is at least six to twelve times greater than the second flexural stiffness FS_2. Most preferably, the first flexural stiffness FS_1 is about eight times greater than the second flexural stiffness FS_2.

Preferably, the third flexural stiffness FS_3 is at least two times greater than the second flexural stiffness FS_2. Thus, the following relationship must be satisfied:

$$(FS_3/FS_2) \cong 2.$$

In club head **10** (as shown in FIG. **3**), the above flexural stiffness relationships are achieved by selecting a certain material with a particular elastic modulus and varying the thickness of the zones. In another embodiment, the flexural stiffness relationships can be achieved by varying the materials of the zones with respect to one another so that the zones have different elastic moduli and the thickness is changed accordingly. Thus, the thickness of the portions can be the same or different depending on the elastic modulus of the material of each portion. It is also possible to obtain the required flexural stiffness ratio through the use of structural ribs, reinforcing plates, and thickness parameters.

Quantitatively, it is preferred that the first flexural stiffness FS_1 is greater than 20,000 lb-in. When the first flexural stiffness is less than 20,000 lb-in excessive deformation of the central region can occur during impact and accuracy is diminished. More preferably, the first flexural stiffness FS_1 is greater than 55,000 lb-in. Preferably, the second flexural stiffness FS_2 is less than 16,000 lb-in. When the second flexural stiffness is greater than 16,000 lb-in the COR the resultant ball velocity is reduced. More preferably, the second flexural stiffness FS_2 is less than 10,000 lb-in and, most preferably, less than 7,000 lb-in.

Referring to FIG. **3**, it is preferred that central portion **36** has a first area that is between about 15% and about 60% of the exterior surface area **32** or face area. The percentage of face area is computed by dividing the area of each zone **36**, **38**, or **40** by the total face area of exterior surface **32**. It should be noted that the total face area of the exterior surface **32** is equivalent to the sum of areas of the zones **36**, **38**, and **40**. In a preferred embodiment, the central zone first area is greater than about 15% and less than about 60% of the total face area. When the central zone **36** is less than 15% of the total face area, then accuracy can be diminished. When central portion **36** is greater than 60% of the face area **32**, then COR can be diminished.

Referring again to FIG. **1**, the club head **10** is further formed so that a center of gravity of the club head has a predetermined relationship with respect to a Cartesian coordinate system with a center located on the exterior surface and coincident with the geometric center GC of the face **16**. The face includes a vertical centerline VCL and a horizontal centerline HCL perpendicular thereto. The geometric face center GC is at the intersection of these centerlines VCL and HCL. Preferably, the geometric center of the central zone **36** is coincident with the club face geometric center GC.

The Cartesian coordinate system is defined when the club head is resting on a flat surface (i.e., at its natural loft) and includes three axes, as illustrated in FIG. **1**. The origin of the Cartesian coordinate system preferably coincides with the geometric center of the hitting face. The X-axis is a horizontal axis positioned tangent to the geometric center of the hitting face with the positive direction toward the heel of the club. The Y-axis is another horizontal axis orthogonal to the X-axis with the positive direction toward the rear of the club. The Z-axis is a vertical axis orthogonal to both the X-axis and Y-axis with the positive direction toward the crown of the club. The center of gravity is preferably located behind and lower than the geometric center of the face.

Referring to FIG. **1**, the location of the center of gravity is defined by coordinates for the center of gravity CG_z, CG_y, and CG_x with respect to the Z, X, and Y axes, respectively. In the vertical direction along the Z-axis, the center of gravity coordinate is designated CG_z, and is spaced a first distance D1 from the geometric face center G along the Z-axis. The first distance D1 is at least about −0.1 inches, and more preferably the first distance D1 is at least about −0.15 inches so that the center of gravity in the vertical direction is below the geometric center GC.

In the horizontal direction along the X-axis, the center of gravity coordinate is designated CG_x, and is spaced a second distance D2 from the geometric face center GC. The second distance D2 is less than about 0.02 inches and greater than −0.02 inches so that the center of gravity in the horizontal direction is spaced from the center GG by no further than the magnitude of distance D2.

Referring to FIG. **1**, along the Y-axis, the center of gravity coordinate is designated CG_y, and is spaced a third distance D3 from the geometric face center GC preferably toward the rear portion **29**. The center of gravity CG_y in the third direction is spaced from the center GC toward the rear portion **29** by no further than the magnitude of the third distance D3. The third distance D3 is preferably equal to or less than about 1.25 inches and, more preferably, less than about 1 inch.

EXAMPLES

These and other aspects of the present invention may be more fully understood with reference to the following non-limiting examples, which are merely illustrative of embodiments of the present invention golf club head, and are not to be construed as limiting the invention, the scope of which is defined by the appended claims.

TABLE 1

FLEXURAL STIFFNESS INFORMATION

Parameter	Comparative Example 1	Comparative Example 2	Comparative Example 3	Inventive Example
Thickness of Center Zone (inches)	0.115	0.130	0.095	0.150
Thickness of First Intermediate Zone (inches)	0.115	0.100	0.098	0.075
Thickness of Second Intermediate Zone (inches)	0.115	0.080	0.100	0.075
Thickness of Perimeter Portion (inches)	0.115	0.150	0.120	0.120
E of All Portions (psi)	1.65E+07	1.65E+07	1.65E+07	1.65E+07
FS of Center Portion (lb-in)	25094	36251	14147	55688
FS of First Intermediate zone (lb-in)	25094	16500	15530	6961
FS of Second Intermediate Zone (lb-in)	25094	8448	16500	6961
FS of Perimeter Zone (lb-in)	25094	55688	28512	28512
FS_1/FS_2	1.0	2.2	0.9	8.0
FS_3/FS_2	1.0	3.4	1.8	4.1

Comparative Examples 1–3 are club heads configured and dimensioned as indicated above with materials so that the zones have certain values. As a result, the ratio of the central zone flexural stiffness and adjacent intermediate zone flexural stiffness for the Comparative Examples are 1.0, 2.2, and 0.9. These ratios are outside of the preferred ratio that ($FS_1/FS_3 \cong 3$) in accordance to one aspect of the present invention. On the other hand, the Inventive Example is configured and dimensioned so that (FS_1/FS_3=about 8). In the examples above, the intermediate zone is defined by a first intermediate zone adjacent the central zone and a second intermediate zone adjacent the first intermediate zone. The perimeter zone is adjacent the intermediate zone(s).

Comparative Examples 1 and 3 have a ratio of FS_3/FS_2 of 1.0 and 1.8, respectively. These ratios are also outside of the preferred ratio ($FS_3/FS_2 \cong 2$) in accordance to another aspect of the present invention. Comparative Example 2 and the Inventive Example satisfy such a ratio with values of about 3.4 and 4.1, respectively.

TABLE 2

CENTER OF GRAVITY INFORMATION

Parameter	Comparative Example 1	Comparative Example 2	Comparative Example 3	Inventive Example
CG_z Location (inches)[1]	0.074	0.074	0.074	−0.120
CG_x Location (inches)[2]	0.133	0.137	0.137	−0.001
CG_y Location (inches)[3]	1.159	1.159	1.182	0.991

[1]Positive z is toward the crown from GC
[2]Positive x is toward the toe from GC
[3]Positive y is toward the back from the GC

The center of gravity for the Inventive Example club head was achieved by the configuration and dimensions of the club head in additional to adding a weight of 31.5 grams to the sole plate. Other known methods of weight manipulation can be used to achieve the inventive center of gravity location as set forth above.

Thus, referring to FIG. 1, in the club head example of the present invention the center of gravity is preferably located along the Z-axis at least 0.10 inches below the geometric face center GC, along the X-axis within 0.01 inches from the geometric face center GC, and along the y-axis within 1.25 inches from the geometric face center GC. The Parameter column of Table 2 describes for each center of gravity location or coordinate the distance that the center of gravity is spaced from the face geometric center GC with respect to a Cartesian coordinate system along particular axes. The centers of gravity for Comparative Examples 1–3 are not located properly with respect to the inventive requirements along the Z- and X-axes. The center of gravity for the Inventive Example is located properly with respect to the inventive requirements in the Z, X, and Y axes.

TABLE 3

TEST RESULTS

Parameter	Comparative Example 1	Comparative Example 2	Comparative Example 3	Inventive Example
Maximum COR	0.807	0.808	0.829	0.830
Average COR	0.765	0.766	0.783	0.789
Maximum Total Distance (yards)	290	286	291	298
Landing Area ($yards^2$)	950	255	1000	341

The test results enumerated in Table 3 were generated using computational techniques, which included finite element analysis models. When computer modeling the exemplary club heads, the following assumptions were made: club head loft of 8.5°; club head mass of 201 grams; and club head material is 6AL-4V titanium alloy. The golf ball used was a two-piece solid ball. Finite element models were used to predict ball launch conditions and a trajectory model was used to predict distance and landing area. The impact condition for the swing used in the total distance and landing area predictions or tests had a club head velocity of 109.1 mph and an attack angle of +2 degrees, the club was oriented such that the vertical plane of the face was at an angle of 8.5 degrees relative to the velocity vector. The impact condition used for club coefficient of restitution (COR) tests was consistent with the USGA Rules for Golf, specifically, Rule 4-1e Appendix II Revision 2 dated Feb. 8, 1999.

COR or coefficient of restitution is one way of measuring ball resiliency. The coefficient of restitution (COR) is the ratio of the velocity of separation to the velocity of approach. In this model, therefore, COR was determined using the following formula:

$$(v_{club\text{-}post} - v_{ball\text{-}post})/(v_{ball\text{-}pre} - v_{club\text{-}pre})$$

where,

$v_{club\text{-}post}$ represents the velocity of the club after impact;

$v_{ball\text{-}post}$ represents the velocity of the ball after impact;

$v_{club\text{-}pre}$ represents the velocity of the club before impact (a value of zero for USGA COR conditions); and

$v_{ball\text{-}post}$ represents the velocity of the ball before impact.

COR, in general, depends on the shape and material properties of the colliding bodies. A perfectly elastic impact has a COR of one (1.0), indicating that no energy is lost, while a perfectly inelastic or perfectly plastic impact has a COR of zero (0.0), indicating that the colliding bodies did not separate after impact resulting in a maximum loss of energy. Consequently, high COR values are indicative of greater ball velocity and travel and total distance. Club heads with thinner faces also have higher COR values, as exhibited by Comparative Example 3 as compared to the Comparative Club 1. However, unexpectedly the Inventive Example has the highest COR. For the inventive club head, preferably the COR is greater than about 0.81, and more preferably greater than about 0.83.

It is expected that as COR increases the ball flight distance will increase and the maximum total distance will also increase. The Inventive Example has the highest COR and also the highest maximum total distance.

It as also expected that as COR increases the shot accuracy will decrease. However, the Inventive Example has the highest COR and the greatest accuracy as illustrated by the data for Landing Area. The Landing Area is an area encompassing the position of nine balls, which impact the club face at various locations. The nine impact locations were equally spaced within a rectangular region 1 inch wide and 0.5 inches high, centered on the geometric center of the club face. The club head of the Inventive Example has a very small Landing Area of 341 square yards. The Comparative Example 3, which is the only Comparative Example with a sufficient COR of at least 0.81, has a Landing Area of 1000 square yards, which is significantly greater than the Landing Area for the Inventive Club. The smaller the landing area, the greater the accuracy of the club.

Several alternative embodiments of the invention are possible. The features of the invention include flexural stiffness for distinct zones or portions of the club face, as

well as the ratio of flexural stiffness between portions. A wide variety of rib configurations and material alternatives may be used to attain the requisite flexural stiffness and flexural stiffness ratio of the face portions.

In FIGS. 3–3B, a preferred embodiment of the club **10** is shown. The club **10** has a face **16** with the following construction. The central zone **36** has a thickness, t_1, of about 0.150 inches, the intermediate zone **38** has thickness, t_2, of about 0.075 inches, and the perimeter zone **40** has thickness, t_3, of about 0.120 inches. Furthermore, the central zone **36** comprises about 20% of the total face surface area and the perimeter zone **40** is less than about 20% of the total face surface area. Each of the three zones **36**, **38**, and **40** has uniform thickness within the zone and are constructed from a single homogeneous material, preferably a titanium alloy, with a Young's modulus (E) of approximately 16.5×10^6 lbs/in^2.

Referring to FIGS. 3–3B, the flexural stiffness, FS_z, can also be defined by the following general equation:

$$FS_z = \sum_{i=1}^{n} \frac{A_i}{\sum_{j=1}^{n} A_j} E_i t_i^3$$

where;

A_i is defined as the area of a constituent within a zone,

E_i is the Young's modulus in pounds per square inch of the constituent within a zone,

$$\sum_{j=1}^{n} A_j$$

represents the total area of the zone,

t_i is the thickness or average thickness in inches of a constituent within a zone,

n is the number of constituents within a zone.

This general equation reduces to the simplified equation $FS_z=Et^3$, stated above when each zone has a uniform thickness and a constant Young's modulus.

Using this simplified equation, the flexural stiffness can be calculated for the central and abutting zones and the flexural stiffness ratio can be computed. The flexural stiffness ratio for the preferred embodiment golf club head **10** is calculated as,

$$FS_c = E_c t_c^3$$
$$= (16.5\times10^6 \text{ lb/in}^2)(0.15 \text{ in})^3$$
$$= 55{,}689 \text{ lb·in, and}$$
$$FS_I = E_I t_I^3$$
$$= (16.5\times10^6 \text{ lb/in}^2)(0.075 \text{ in})^3$$
$$= 6{,}961 \text{ lb·in,}$$

where PS_C is the flexural stiffness of central region **36** (also denoted FS_1 as herein) and FS_I is the flexural stiffness of intermediate region **38** (also denoted FS_2 as herein). These values are also reported in Table 1, above. Hence, the ratio of flexural modulus of golf club head **10** is

$$(FS_C/FS_I)=8.0.$$

In FIG. **6**, an alternate embodiment of the club head **110** is shown to illustrate an alternate construction of hitting face **116** that results in a similar flexural stiffness ratio of the central portion to the abutting intermediate zone as the embodiment of FIG. **3**. In the club head **110**, the face **116** has an elliptically shaped central zone **136** an adjacent intermediate zone **138**. The central zone **136** occupies about 30 percent of the total face surface area.

Referring to FIGS. 7–7B, the central zone **136** includes a ribbed support structure **137***a* (shown in phantom) that extends from the interior surface of the face. The asterisk-shaped ribbed structure, which comprises a plurality of ribs or legs, stiffens the central zone. The thickness of the ribbed portion **137***a* of the central zone t_{1A} is about 0.225 inches. The width of the rib, w, is about 0.085 inches. The thickness of the remaining portion **137***b* between the ribs of the central zone t_{1B} is about 0.09 inches. The ribbed structure **137***a* is defined such that it comprises about 25 percent of the surface area of the central zone. The intermediate zone **138** has a uniform thickness, t_2, of about 0.075 inches and extends to the boundary of the face **116** with no defined perimeter zone. The face **116** is preferably made of a homogeneous titanium alloy with a Young's modulus (E) of 16.5×10^6 lbs/in^2.

Referring to FIGS. 6–7B, the flexural stiffness ratio between the central region **136** and the abutting intermediate zone **138** is computed, as follows:

Area of the elliptical central region **136** is $A_C=\pi\times b\times a$, where "b" is ½ of the major axis of the ellipse and "a" is ½ of the minor axis of the ellipse. When the major axis is 2 inches and the minor axis is 1 inch, the area of the central region is 1.57 in^2.

The area of the ribs is simply its width (WI=0.085 inch) times its length (LI=4.6 inch) or A_r=WI×LI=0.39 in^2.

Hence, the non-rib area $A_{NR}=A_c-A_r=(1.57-0.39)=1.18$ in^2.

Thus, the general flexural stiffness equation stated above reduces to

$$FS_c=(A_r/A_c)E(t_{1A})^3+(A_{NR}/A_C)E(t_{2B})^3,$$

$$FS_c=(0.39/1.57)(16.5\times10^6 \text{ lb/in}^2)(0.225 \text{ in})^3+(1.18/1.57)(16.5\times10^6 \text{ lb/in}^2)(0.090 \text{ in})^3,$$

$$FS_c=56{,}008 \text{ lb·in, and}$$

$$FS_I = E(t_2)^3,$$
$$= (16.5\times10^6 \text{ lb/in}^2)(0.075 \text{ in})^3,$$
$$= 6{,}961 \text{ lb·in.}$$

Hence, $(FS_c/FS_I)=8.05$.

It should be noted that ribs, welts, pimples, or other discrete thickness variations within a zone are handled as discrete elements within a particular zone and are computed in accordance with the governing general equation for flexural stiffness discussed above.

In FIG. **8**, an alternate embodiment of the club head **210** is shown to illustrate an alternate construction of face **216** that results in a similar flexural stiffness ratio of the central zone to the abutting intermediate zone as the embodiment of FIG. **3**. In the club head **210**, the face **216** has a central zone **236** and an adjacent intermediate zone **238**. The central zone **236** is about 30 percent of the total face surface area. The club head **210** does not have a defined perimeter zone.

Referring to FIGS. 9–9A, the central zone **236** has a uniform thickness of t_1 of about 0.140 inches. The intermediate zone **238** has a continuously tapered thickness from the face perimeter inward to the central zone **236**. The thickness of the intermediate zone **238** is defined to change linearly.

The intermediate zone **238** has an inner thickness, t_{2A}, of about 0.07 inches at the boundary of the central zone **236** and the intermediate zone **238**. The intermediate zone **238** has an outer thickness, t_{2B}, of about 0.10 inches. The outer thickness is at the face perimeter. In instances of non-uniform thickness, within a zone, and primarily in relation to a continuous tapered zone, an average thickness may be used to compute the flexural stiffness for the zone. This approximation simplifies the calculation and is physically based on elastic shell theory.

In this embodiment, two different homogenous materials are used. The central zone **236** is preferably made from a stainless steel having a Young's modulus of 30.0×10^6 lbs/in^2 and the adjacent intermediate zone **238** is made from a titanium alloy with a Young's modulus of 16.5×10^6 lbs/in^2.

Referring to FIGS. 8–9A, the flexural stiffness ratio between the central and adjacent zone is computed.

$$FS_c = E_c(t_1)^3,$$
$$= (30\times10^6 \text{ lb/in}^2)(0.140 \text{ in})^3,$$
$$= 82{,}320 \text{ lb·in},$$
$$FS_I = E_I((t_{2A}+t_{2B})/2)^3,$$
$$= (16.5\times10^6 \text{ lb/in}^2)((0.1+0.07)\text{in}/2)^3,$$
$$= 10{,}133 \text{ lb·in}.$$

Hence, (FS_c/FS_I)=8.12.

In FIG. **10**, an alternate embodiment of the club head **310** is shown to illustrate an alternate construction of face **316** that results in a similar flexural stiffness ratio of the central zone to the abutting intermediate zone as the embodiment of FIG. **3**. In the club head **310**, the face **316** has an elliptically shaped central zone **336** and an adjacent intermediate zone **338**. The central zone **336** is formed using two materials **337***a* (shown in phantom) and **337***b* (shown in phantom).

The central zone **336** has a uniform thickness, t_1, of about 0.140 inches. The first material **337***a* is a titanium alloy with a Young's modulus of 16.5×10^6 lbs/in^2. The second material **337***b* is stainless steel and has a Young's modulus of 30×10^6 lbs/in^2. The central zone **336** comprises about 60 percent stainless steel.

Furthermore, the central zone **336** is elliptically shaped and comprises about 25 percent of the total face surface area. The intermediate zone **338** with the perimeter zone **340** comprises of no more than 20 percent of the total face surface area. The intermediate zone has a uniform thickness, t_2, of about 0.08 inches and is constructed from the same titanium alloy as the central zone **336**.

Referring to FIGS. **10**–**11A**, the flexural stiffness ratio between the central region **336** and intermediate zone **338** can be computed, as follows.

Using the equation for determining the area for an ellipse, stated above, when the major axis is about 1.8 inch and the minor axis is about 0.9 inch, the area of central region **336** is A_C=1.272 in^2. As discussed above, the area of stainless steel (A_S) is 60 percent and the area of titanium or non-steel (A_{NS}) is 40 percent.

$$FS_c=(A_s/A_c)E_s(t_1)^3+(A_{NS}/A_C)E_t(t_1)^3,$$
$$FS_c=(0.60)(30\times10^6 \text{ lb/in}^2)(0.14 \text{ in})^3+(0.40)(16.5\times10^6 \text{ lb/in}^2)(0.14 \text{ in})^3,$$
$$FS_c=67{,}502 \text{ lb·in, and}$$
$$FS_I = E_I(t_2)^3,$$
$$= (16.5\times10^6 \text{ lb/in}^2)(0.080 \text{ in})^3,$$
$$= 8{,}448 \text{ lb·in}.$$

Hence, (FS_c/FS_I)=8.0.

The golf club head embodiments **10**, **110**, **210**, and **310** discussed in FIGS. **1**–**11A** demonstrate four unique face constructions which result in a similar flexural stiffness ratio, where the central zone to the adjacent zone ratio is greater than or equal to three and, more particularly, about eight. In cases where the face construction is uncertain due to manufacturing tolerances or methods or for other possible reasons, a nondestructive test method of determining the flexural stiffness ratio for a given face construction may be used.

Referring to FIG. **12**, a typical club **410** is shown with an unknown face thickness profile. Preferably, something is known regarding the construction materials of the face or has been determined experimentally through test methods known to those of ordinary skill in the art. In FIG. **12**, a random distribution of points is shown on face **416**. This distribution is referred to herein as a "point cloud" or predetermined point distribution. Points labeled C indicate a position in the central zone **436**. Points labeled I indicate a position in the intermediate zone **438**. Points labeled P indicate a position in the perimeter zone **440**. The numbers following the position letters "C", "I" or "P" indicate relative face position.

Using the defined point cloud, an ultrasonic measurement device **450** (as shown in FIG. **13**) can be used to map the face **416** thickness profile. The point cloud technique has the advantage of capturing discrete variations in face thickness such as the presence of ribs or abrupt thickness changes. One preferred ultrasonic measurement device includes a Panametrics Model 25DL ultrasonic thickness device **455** and a Panametrics model M208 probe **460**. The sensor or device **455** and the probe or transducer **460** are commercially available from Panametrics, Inc. of Waltham, Mass.

Referring to FIG. **12**, the face thickness data obtained from the ultrasonic measurement, along with material modulus information, is then used to define the central, intermediate and possibly perimeter zones. The central zone **436** is defined by constructing an area comprising of a specific percentage of the total face surface area and including the geometric center GC. The point cloud thickness data within the defined zone is then averaged or broken into distinct elements within the zone. If the latter is required, the area percentages for the elements within the zone are calculated. The calculation for FSz previously outlined is then carried out to determine the flexural stiffness ratio between the central and adjacent zone **436** and **438**, respectively.

The following example illustrates the technique. In Table 4, random face thickness measurements are shown for titanium alloy club **410** (as shown in FIG. **12**) with an unknown face thickness profile. The technique described above is used.

TABLE 4

ULTRASONIC FACE THICKNESS DATA

Position	Thickness
C1	0.132
C2	0.127
C3	0.131
C4	0.125
C5	0.136
C6	0.130
C7	0.127
C8	0.129
C9	0.133
C10	0.138
C11	0.134
C12	0.131
I1	0.102
I2	0.103
I3	0.098
I4	0.096
I5	0.088
I6	0.089
I7	0.089
I8	0.094
I9	0.097
I10	0.099
I11	0.100
I12	0.103
I13	0.106
I14	0.102
I15	0.105
I16	0.101
I17	0.100
I18	0.103
I19	0.107
I20	0.106
P1	0.110
P2	0.115
P3	0.117
P4	0.119
P5	0.120
P6	0.114
P7	0.117
P8	0.109
P9	0.108
P10	0.111
P11	0.115
P12	0.118
P13	0.109
P14	0.108
P15	0.112
P16	0.112
P17	0.115
P18	0.109
P19	0.117
P20	0.120

FIG. **12** shows the measured data points and the projected central, intermediate and perimeter zones **436**, **438**, and **440**. Based on these projected areas, the percentage of each zone can be estimated or computed more accurately by other techniques, such as face scanning. The data defines three zones, the actual central zone with an average thickness of 0.131 inches; the actual intermediate zone with an average thickness of 0.099 inches, and the perimeter zone with an average thickness of 0.114 inches. Furthermore, the area of the central zone has been estimated to be about 23 percent of the total face surface area, and the perimeter zone is estimated to comprise of about 35 percent of the total face area. Based on this information a flexural stiffness ratio can be computed as set forth below.

With regard to the calculation of face flexural stiffness and the flexural stiffness ratio, the aforementioned embodiments and point cloud example all consider hitting faces, which possess isotropic material property and symmetry with regard to a mid-surface of the face structure. Material isotropy, however, in not a necessary condition of the invention. And the invention can include club heads with anisiotropic materials. The flexural stiffness or the flexural stiffness ratio can be used with anisiotropic constructions. These calculations would still be applicable but of a more general form, as discussed below.

The notion of symmetry with regard to a mid-surface of the face simplifies the calculations of flexural stiffness. The calculation of flexural stiffness for asymmetric shell structures with respect to the mid-surface is common in composite structures where laminate shell theory is applicable. Here the Kirkhoff shell assumptions are applicable. Referring to FIG. **14**, an asymmetric isotropic laminate **500** is shown with N lamina or layers **502**. Furthermore, the laminate is described to be of thickness, t, with x_i being directed distances or coordinates in accordance with FIG. **14**. The positive direction is defined to be downward and the laminate points x_i defining the directed distance to the bottom of the k^{th} laminate layer. For example, x_0=−t/2 and x_N=+t/2 for a laminate of thickness t made comprised of N layers.

Further complexity is added if the lamina can be constructed of multiple materials, M. In this case, the area percentage, Ai is included in the flexural stiffness calculation, as before in a separate summation over the lamina. The most general form of computing the flexural stiffness in this situation is, as stated above:

$$FS_z = \sum_{i=1}^{n} \frac{A_i}{\sum_{j=1}^{n} A_j} E_i t_i^3$$

Due to the geometric construction of the lamina about the mid-surface, asymmetry results, i.e., the laminate lacks material symmetry about the mid-surface of the laminate. However, this asymmetry does not change the calculated values for the flexural stiffness only the resulting forces and moments in the laminate structure under applied loads. An example of this type of construction would be a titanium alloy face of uniform thickness and first modulus E_t, where the central zone is backed by a steel member of width half the thickness of the titanium portion, and having second modulus E_s. In this example, the flexural stiffness can be approximated by the simplified equation, as follows:

$$FS_z = \frac{1}{3}\sum_{i=1}^{M} [E(x_k^3 - x_{k-1}^3)]_i$$

$$FS_z = \tfrac{1}{3}\{[E_s(x_o^3 - x_1^3)] + E_t(x_1^3 - x_2^3)]\}$$

here, x_o=−t/2, x_1=t/2−WI and x_2=t/2, substitution yielding

$$FS_z = \tfrac{1}{3}\{[E_s((-t/2)^3 - (t/2 - WI)^3)] + E_t((t/2)^3)]\}$$

If t=0.125, then WI=0.083 and FS of this zone is 3,745 lb·in, where the thickness of the steel layer is about one-half of the thickness of the titanium layer.

Referring to FIG. **15**, a testing apparatus **650** for measuring inertance is schematically illustrated. Generally, inertance is a frequency response. More specifically, inertance is a measure of the stiffness of a structure, in this instance the club face, at various frequencies of vibration. The units of

inertance are acceleration units over force units. A preferred first resonant frequency for the inventive face is located where the inertance is maximized.

The test apparatus **650** includes club head **652**, a rigid mass **654**, an accelerometer **656**, and an impact hammer **658**. The mass **654** is preferably a cylindrical steel rod with a diameter of 1 inch. Referring to FIGS. **15** and **15**A, the mass **654** preferably has a cylindrical cavity **659** at one end for receiving the accelerometer **656** and a slot **660** to accommodate the cable **662**. The accelerometer **656** is connected to the geometric center of the face of the club head **652** with a high modulus adhesive **657**, such as a cyanoacrylate based adhesive, Loctite 409, available from Loctite Corp., Newington, Conn. The mass **654** is then placed over the accelerometer **656** and also secured to the club face with cyanoacrylate adhesive. The combined mass of the mass **654** and the accelerometer **656** should equal the mass of a golf ball or 1.62 oz. The impact hammer **658** has an integral force transducer **658***a* and is movable toward and away from the free end **654***a* of the rigid mass, as indicated by the arrow I, to impact the mass **654**, which is attached to the club head face at the geometric center. The impact force or excitation force is normal to the club face, and upon impact is transmitted to the hitting face through the mass **654**.

The testing apparatus **650** further includes a junction box and ICP power supply **660** and cables **662** electrically connected to the accelerometer **656** and the impact hammer transducer **658***a*. The junction box and ICP power supply **660** is in turn connected to a digital signal processing board **664**, located within a computer **665** with signal processing software **667**. The digital signal processing board **664**, computer **665** and software **667** are used to condition frequency signals and calculate the frequency response functions. The accelerometer **656**, transducer **658***a*, junction box and ICP power supply **660**, cables **662**, digital signal processing board **664**, computer **665**, and software **667** are commercially available and one of ordinary skill in the art can readily identify and obtain inertance values for golf clubs using these components. Typically, the data from 20 impacts are averaged to reduce noise and improve measurement accuracy. The following TABLE 5 lists specific model numbers for the vibration equipment shown in FIG. **13**.

TABLE 5

VIBRATION EQUIPMENT

Reference Number	Part	Model #	Supplier
656	Accelerometer	352A10	Modal Shop of Cincinnati, OH
658	Impact Hammer	086C01	Modal Shop
662	Cables	002T01	Modal Shop
660	Junction Box & ICP power	BNC 2140	National Instruments of Dallas, TX
664	DSP Board	NI 4551	National Instruments
665	Computer	Dell Optiplex Gxi	Dell Computers of Round Rock, TX
667	Software	Virtual Bench DSA 2.5.1	National Instruments

Referring to FIG. **16**, a graph of inertance versus frequency for a conventional club head is shown. The conventional club head is a Callaway Great Big Bertha War Bird with an eight degree loft. The inertance I shown is the result of testing using apparatus **650** of FIG. **15**. The point I_1 at a frequency of 3330 Hertz represents the first primary resonant frequency, which occurs at the first primary maxima inertance for the inertance function I. A maxima, which does not represent a primary resonant natural frequency of the face, is also present in FIG. **16** at a frequency of 2572 Hertz, which is the point I_2. These secondary maxima I_2 are characterized by inertance transitions of a magnitude of less than 10 decibels. These secondary maxima may be due to crown, sole or skirt vibrations that are not acting perpendicular to the plane of the club face. Secondary maxima do not correlate with COR and ball velocity, since the vibration response is either small in magnitude or alternately not coincident with ball response. The COR for the conventional club head tested was measured in accordance with USGA, Rule 4-1e Appendix II Revision 2 dated Feb. 8, 1999 and was found to be 0.785. The preferred first primary resonant frequency of vibration is defined by the following relationship:

$$1/(2\times\text{contact duration}) < I_1 < 3/(2\times\text{contact duration})$$

The contact duration is the time interval during which the ball is in contact with the club face. The contact duration for a typical driver impact is about 500 microseconds (500×10^{-6} second). Thus, the preferred primary resonant frequency of vibration for the club head is between about 1000 and 3000 Hz. The closer the contact time is to the lower limit, the higher the COR and thus the higher the rebound ball velocity. More preferably, the first primary resonant frequency is less than 2900 Hz.

FIG. **17** illustrates the inertance function of the inventive club head. The first primary resonant frequency is at 2632 Hz, and the COR of this inventive club was measured to be 0.824. The COR of the invention club is greater than the conventional club of FIG. **16**, and therefore will provide greater ball rebound velocity.

Several example club heads were produced with two commercially available titanium alloys 6AL-4V and SP700. The clubs were produced with a variety of uniform face thickness. FIG. **18** illustrates that as face thickness is reduced for a given titanium alloy the COR increases in a linear fashion. However, different titanium alloys with slightly different moduli have distinct trend lines and thickness alone is insufficient to predict COR. FIG. **19** illustrates a plot of COR versus first primary resonant frequency for the same set of club heads as those of FIG. **18**. FIG. **18** illustrates that first primary resonant frequency is predictive of COR regardless of titanium alloy. The first primary resonant frequency of a club head may be used as a quality control factor to ensure compliance with USGA COR rules.

In accordance to another embodiment of the present invention, hitting face **16** is divided into two or more non-concentric regions having distinct flexural stiffness as illustrated in FIGS. **20**–**23**. Club head **510** comprises toe **18**, heel **20**, sole plate **22**, hosel **24**, crown **28**, and back portions similar to the other inventive clubs described above. Club head **510** further has a hitting face **516** that comprises an upper or crown face portion **520** and a lower or sole face portion **522**. Club head **510** may also have an optional perimeter portion **540**. Preferably, the flexural stiffness of the crown face portion **520** is different than the flexural stiffness of the sole face portion **522**.

In accordance to one aspect, the flexural stiffness of crown face portion **520** is preferably about one half of the flexural stiffness of the sole face portion **522**. In other words, the flexural stiffness of hitting face **516** varies and more specifically increases in the direction from crown **28** to sole **22**. During an on-center or near center impact with a golf ball, as the hitting face deforms, crown face portion **520** deforms more than sole face portion **522** due to its lower flexural stiffness. This shift in the deformation causes a correspond-

ing increase in launch angle of the golf ball, when compared to a similar golf club with a similar club loft angle but without the varying crown-to-sole flexural stiffness.

The increase in the launch angle of the golf ball achieved by the crown-to-sole flexural stiffness variation depends on a number of factors, including the location of the impacts on the hitting face and the flexural stiffness at the location of the impacts. Conversely, the launch angle of the golf ball can be reduced by reversing the crown-to-sole flexural stiffness variation, i.e., the flexural stiffness of the crown face portion **520** is higher than the flexural stiffness of the sole face portion **522**. In this embodiment, the launch angle decreases because the sole face portion deforms more than the crown face portion.

Preferably, the flexural stiffness (Et^3) for the crown face portion **520** of hitting face **516** is between about 8,500 lb·in and about 60,000 lb·in, and the flexural stiffness of the sole face portion **522** is about twice (200%) of the flexural stiffness of the crown face portion **520** or less, such that the launch angle of the golf ball increases. On the other hand, the flexural stiffness of the sole face portion is about one-half (50%) of the flexural stiffness of the crown face portion or more such that the launch angle of the golf ball decreases. Suitable ratios of flexural stiffness between these portions include 4::1, 1::4, 2::3 or 3::2.

In accordance to another aspect of the present invention, as illustrated in FIG. **21** hitting face **516** of club head **510** comprises heel face portion **524** and toe face portion **526**, such that the flexural stiffness of hitting face **516** varies in the heel-to-toe direction. Similar to the embodiment shown in FIG. **20**, this hitting face also selectively and locally deforms to direct the angle of the golf ball in a desirable lateral direction. More specifically, for on-center or near-center impacts when the flexural stiffness of heel face portion **524** is lower than the flexural stiffness of toe face portion **526**, the heel face portion deforms more to direct the angle of the ball more to the left of a right-handed golfer's body to compensate a tendency to slice or hook the ball to the right. On the other hand, when the flexural stiffness of the toe face portion **526** is lower than the flexural stiffness of the heel face portion **524**, the toe face portion deforms more to direct the golf ball to the right of a right-handed golfer's body to compensate for a tendency to slice or hook the ball to the left.

Preferably, the flexural stiffness (Et^3) for the heel face portion **524** of hitting face **516** is between about 8,500 lb·in and about 60,000 lb·in, and the flexural stiffness of the toe face portion **526** is about twice (200%) of the flexural stiffness of the heel face portion **524** or less, such that the flight of the golf ball is directed to the left. On the other hand, the flexural stiffness of the toe face portion is about one-half (50%) of the flexural stiffness of the heel face portion or more such that the flight of the golf ball is directed to the right. Suitable ratios of flexural stiffness between these portions include 4::1, 1::4, 2::3 or 3::2.

In accordance to another aspect of the present invention, the advantages of the hitting face shown in FIG. **20** and in FIG. **21** can be realized in a single hitting face, as illustrated in FIG. **22**. Here, hitting face **516** comprises four portions: crown-heel portion **528**, crown-toe portion **530**, sole-toe portion **532** and sole-heel portion **534**. The flexural stiffness of hitting face **516** can vary in both the crown-to-sole and heel-to-toe directions. The flexural stiffness can either increase or decrease in either direction. Hence, the advantages of altering the vertical launch angle and the lateral direction of the flight of a golf ball can be realized on a single golf club head.

Preferably, the flexural stiffness of the crown-heel portion **528** is between about 8,500 lb·in and about 60,000 lb·in. The flexural stiffness of the crown-toe portion **530** is preferably about 70% to about 130% of the flexural stiffness of crown-heel portion **528**. The flexural stiffness of the sole-toe portion **532** is preferably about 50% to about 130% of the flexural stiffness of crown-heel portion **528**. The flexural stiffness of the sole-heel portion **534** is preferably about 70% to about 200% of the flexural stiffness of crown-heel portion **528**.

Alternatively, the hitting face **516** may comprise two or more non-concentric portions that make up any regular or irregular shape, such as the embodiment illustrated in FIG. **23**. Furthermore, the boundaries between the non-concentric regions do not have to be substantially horizontal or substantially vertical.

Another readily apparent advantage of this embodiment is that it can reduce the manufacturing costs for golf clubs. The flexural stiffness of the hitting face can be altered in accordance to the present invention to achieve the effect of multiple lofts for a given head club design having a fixed loft angle. Tooling for a single mold with various face cavity inserts can produce a family of club heads having varying effective loft angles, albeit with a same exterior loft angle.

In accordance to another embodiment of the present invention, the advantages of the embodiments shown in FIGS. **1–19**, i.e., having a rigid central portion **36**, **136**, **236**, **336** or **446** and relatively flexible intermediate portion **38**, **138**, **238**, **338** or **448**, so that upon impact the intermediate portion deforms to provide high initial velocity while the central portion is substantially un-deformed so that the ball flies on-target ($FS_c/FS_I \geqq 3$), among others, can be combined with the advantages of the embodiments shown in FIGS. **20–23**, i.e., vertical and lateral control of the ball's flight. As illustrated in FIGS. **24–25**, golf club head **610** comprises hitting face **616**, which has a central portion **36**, **136**, **236**, **336** or **436** surrounded by an intermediate portion comprising crown intermediate portion **620** and sole intermediate portion **622**. Face **616** may also comprise an optional perimeter region (not shown). Preferably, the ratio of flexural stiffness between the central region and any portion of the intermediate region is greater than or equal to about 3.0, and more preferably between about 6.0 and about 12.0. In other words, this ratio between the central region and the crown intermediate portion **620** and between the central region and the sole intermediate portion **622** is greater than or equal to about 3.0, and more preferably between about 6.0 and about 12.0.

In this embodiment, preferably the flexural stiffness of the two intermediate portions **620** and **622** are different. Crown intermediate portion **620** may have a lower flexural stiffness than sole intermediate portion **622**, or vice versa, depending on the desired launch angle of the ball. In one non-limiting example, the ratio of flexural stiffness between the central region and the crown intermediate portion **620** is about 9.0, while the same ratio between the central region and the sole intermediate portion is about 6.0 to control the launch angle of the golf ball.

On the other hand, to control the lateral launch angle of the golf ball while maintaining the high initial velocity produced by the ($FS_c/FS_1 \geqq 3$) flexural stiffness ratio, hitting face **616** may comprise central region **36**, **136**, **236**, **336** or **436** and an intermediate region comprising heel intermediate portion **624** and toe intermediate portion **626**, as shown in FIG. **26**. Preferably, the ratio of flexural stiffness between the central region and any portion of the intermediate region is greater than or equal to about 3.0, and more preferably

between about 6.0 and about 12.0. In other words, this ratio between the central region and the heel intermediate portion **620** and between the central region and the toe intermediate portion **622** is greater than or equal to about 3.0, and more preferably between about 6.0 and about 12.0, or greater than 12.0.

In this embodiment, preferably the flexural stiffness of the two intermediate portions **624** and **626** are different. Heel intermediate portion **620** may have a lower flexural stiffness than toe intermediate portion **622**, or vice versa, depending on the desired lateral angle of the ball. In one non-limiting example, the ratio of flexural stiffness between the central region and the heel intermediate portion **620** is about 9.0, while the same ratio between the central region and the toe intermediate portion is about 6.0 to control the lateral angle of the golf ball.

In accordance to another aspect of the invention, hitting face **616** may comprise a central region, as discussed above, and an intermediate region comprising four portions: crown-heel intermediate portion, crown-toe intermediate portion, sole-toe intermediate portion and sole-heel intermediate portion, similar to the embodiment shown in FIG. **22**. Each intermediate portion preferably has different flexural stiffness to vary the launch and lateral angle of the golf ball. Furthermore, the ratio of flexural stiffness between the central region and each of the intermediate portions is greater than or equal to about 3.0, and more preferably between about 6.0 and about 12.0.

While various descriptions of the present invention are described above, it should be understood that the various features of each embodiment can be used alone or in any combination thereof. Therefore, this invention is not to be limited to only the specifically preferred embodiments depicted herein. Further, it should be understood that variations and modifications within the spirit and scope of the invention may occur to those skilled in the art to which the invention pertains. For example, the face and/or individual portions can have thickness variations in a step-wise or continuous fashion. Other modifications include a perimeter portion that has a thickness that is greater than or less than the adjacent, intermediate portion. In addition, the shapes of the central, intermediate, and perimeter portions are not limited to those disclosed herein. Accordingly, all expedient modifications readily attainable by one versed in the art from the disclosure set forth herein that are within the scope and spirit of the present invention are to be included as further embodiments of the present invention. The scope of the present invention is accordingly defined as set forth in the appended claims.

What is claimed is:

1. A golf club head adapted for attachment to a shaft and having a hitting face, wherein the hitting face comprises a directional control portion, said directional controlled portion comprises two or more non-concentric zones having different flexural stiffness, such that when the hitting face impacts a golf ball the zones exhibit different degrees of deformation to selectively control the direction of the flight of the golf ball, wherein the hitting face further comprises a central portion disposed within the directional control portion such that the central portion contains a geometric center of the hitting face and wherein the flexural stiffness of the central portion is at least about three times greater than the flexural stiffness of the directional control portion.

2. The golf club head of claim **1**, wherein the flexural stiffness of the central portion is at least about six times greater than the flexural stiffness of the directional control portion.

3. The golf club head of claim **2**, wherein the flexural stiffness of the central portion is at least about twelve times greater than the flexural stiffness of the directional control portion.

4. The golf club head of claim **1**, further comprising a perimeter portion disposed around the directional control portion, wherein the flexural stiffness of the perimeter portion is at least about two times greater than the flexural stiffness of the directional control portion.

5. The golf club head of claim **1**, wherein the hitting face comprises a laminate material.

6. The golf club head of claim **1**, wherein the directional control portion comprises an upper too zone and a lower heel zone.

7. The golf club head of claim **1**, wherein the directional control portion comprises a lateral heel zone and a lateral toe zone.

8. The golf club head of claim **1**, wherein the directional control portion comprises four zones, an wherein the zones are delineated by a vertical center line and a horizontal center line of the hitting face.

9. The golf club head of claim **1**, wherein the flexural stiffness of a first zone of said two or more zones is between about 8,500 lb·in to about 60,000 lb·in.

10. The golf club head of claim **9**, wherein the flexural stiffness of a second zone of said two or more zones is about 0.5 times about two times the flexural stiffness of the first zone.

11. The golf club head of claim **9**, wherein the flexural stiffness of a third zone of said two or more zones is about 0.7 times to about 1.3 times the flexural stiffness of the first zone.

12. The golf club head of claim **9**, wherein the flexural stiffness of a fourth zone of said two or more zones is about 0.7 times to about two times the flexural stiffness of the first zone.

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